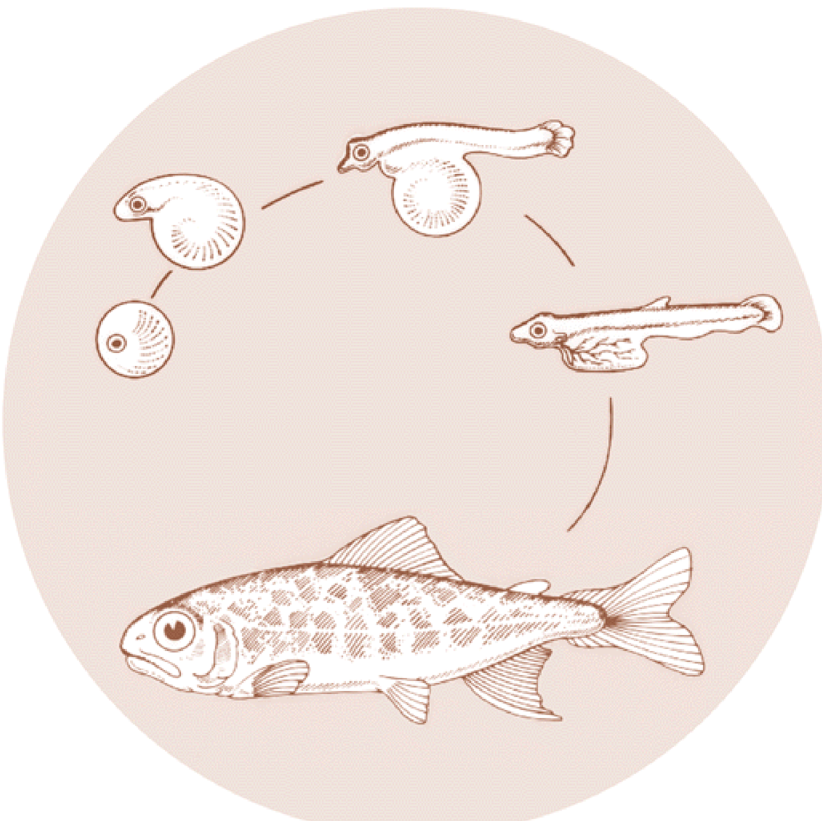
WILLAMETTE OXYGEN SUPPLEMENTATION STUDIES, AMMONIA ANALYSIS AND ADULT RETURNS

Fish Culture Section

September 30, 1994 to September 29, 1995

Annual Progress Report



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WILLAMETTE OXYGEN SUPPLEMENTATION STUDIES, AMMONIA ANALYSIS AND ADULT RETURNS

Fish Culture Section

Annual Progress Report
September 30, 1994 to September 29, 1995

Prepared by:

R. D. Ewing

Prepared for:

U.S. Department of Energy
Bonneville Power Administration
Environment, Fish and Wildlife
PO Box 3621
Portland, Oregon 97208

Project No. 88-160
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INTRODUCTION

Hydropower development and operations in the Columbia River basin have caused the loss of 5 million to 11 million salmonids. An interim goal of the Northwest Power Planning Council is to reestablish these historical numbers by doubling the present runs from 2.5 million adult fish to 5.0 million adult fish. This increase in production will be accomplished through comprehensive management of both wild and hatchery fish, but artificial propagation will play a major role in the augmentation process. The current husbandry techniques in existing hatcheries require improvements that may include changes in rearing densities, addition of oxygen, removal of excess nitrogen, and improvement in raceway design. Emphasis will be placed on the ability to increase the number of fish released from hatcheries that survive to return as adults.

Rearing density is one of the most important elements in fish culture. Fish culturists have attempted to rear fish in hatchery ponds at densities that most efficiently use the rearing space available. Such efficiency studies require a knowledge of cost of rearing and the return of adults to the fisheries and to the hatchery.

It is widely accepted that the limitations on survival imposed by rearing densities are dependent upon oxygen availability. The models of Westers (1970), Liao (1971), and Banks et al. (1979) are based on the limitations of oxygen availability at various densities, temperature, and sizes of the fish being reared. In the past oxygen limitations has been overcome by increased flow, but in recent years, addition of oxygen to the raceways has become an acceptable alternative.

In spite of the acceptance of oxygen as the limiting factor in fish culture at the present time, there has been little information on the relationship between oxygen availability to cultured salmon and their subsequent survival to adulthood after release. This project will extend that information by examining the effects of oxygen supplementation in a surface water hatchery on the rearing and survival of spring chinook salmon.

The first four years of the project examined the operational aspects of the use of oxygen, the effects of water quality on oxygen utilization, and overall quality of fish reared at high densities with supplemental oxygen. Raw data and preliminary analyses for four years of juvenile rearing have already been described (Ewing and Sheahan 1990; Ewing and Sheahan 1991; Ewing and Sheahan 1992; Ewing et. al. 1993; Ewing et al. 1994). The next series of reports will provide detailed analyses of water quality and growth parameters during the rearing years and will tabulate the recovery of marked adults as they become available.

The present report describes the results from analysis of ammonium and nitrogenous waste production in experimental raceways during the four years of experimental rearing. A manuscript summarizing these analyses is being prepared for publication. Because of the length of the present report, a review of the abundant literature on nitrogen excretion in salmonids will not be presented at this time but will be included in a future report.

METHODS AND MATERIALS

Fish Culture

Spring chinook salmon (Oncorhvnchus tshawvtscha) adults were collected at the Dexter holding ponds below the Dexter Dam, 15 miles east of Eugene. The adults were hauled to Willamette Hatchery in Oakridge, Oregon, and were held in a 300 foot long by 15 feet wide excavated rock and earth pond supplied with water from Salmon Creek at a flow of about 10,600 liters per minute. Approximately 1600 adults were held throughout the summer. Spawning occurred from September through October and each egg-take was incubated separately. Juveniles released in the fall of their first year came from the earliest egg-takes. The fish used for this project were derived from later spawnings in order not to exceed the size desired at release. These fish were ponded in groups by hatching dates.

Juvenile fish were taken randomly from different egg-take groups and marked with adipose-fin clips and coded-wire tags. At the time of tagging (during the month of July) they were introduced into experimental raceways. Because of the complexity of the experimental design, the letters A through G are used to designate the different test groups (Table 1). Subscripts represent replicates. Ideal experimental conditions for each raceway are given in Table 2.

Table 1. Designations and pond number for experimental ponds at Willamette Hatchery.

Designation	Pond	Characteristics
A_1	7	Normal density, no oxygen supplementation
A_2	17	Replicate
B_1	6	Half density, no oxygen supplementation
B_2	16	Replicate
C_1	8	Normal density, oxygen supplementation
C_2	18	Replicate
D_1	9	Triple density, oxygen supplementation
D_2	19	Replicate
E_1	30N	Michigan system, first pass, oxygen supplementation
E_2	30s	Replicate
F_1	20N	Michigan system, second pass, oxygen supplementation
F_2	20s	Replicate
G_1	10s	Michigan system, third pass, oxygen supplementation
G_2	10N	Replicate

Table 2. Ideal characteristics of experimental ponds at Willamette Hatchery[a].

Group	Number of fish	Final pounds	Inflow gpm	Load pounds/gpm	Volume ft^3	Density pounds/ft^3
A	36,000	3,600	500	7.2	3,700	0.970
B	18,000	1,800	500	3.6	3,700	0.486
C	36,000	3,600	500	7.2	3,700	0.970
D	108,000	10,800	500	21.6	3,700	2.919
E,F,G	54,000	5,400	750	7.2	1,850	2.919

[a] Characteristics given are approximate and should be compared with experimental numbers provided in the Results section.

When required, oxygen was added to the raceways through sealed contact columns (Westers et. al., 1988). Modifications of the design to fit site-specific requirements were determined before experimental rearing began (Fish Factory, 1990). No packing media or dispersion plates were used in the columns. In raceways with supplemental oxygen, dissolved oxygen in the raceway effluent was maintained at 100% of saturation. Oxygen flow into the contact column was increased or decreased manually using a Brooks rotometer.

Water flow into the ponds was adjusted by gate valves on the main water supply line to the hatchery. Flow was measured by exact measurements of the pond dimensions and determining the length of time required for a particular flow to increase the depth of the raceway by one inch. An inch of depth represented 920 gallons or 123 ft^3. The time required for a flow of 500 gpm to increase the depth by 1 inch was then calculated as (920/500)*60 or 110 seconds.

The error associated with a measurement of this sort concerns mostly the exact time required to reach the 1 inch mark on the pond wall. The general feeling from making the measurements that the error was between 5 and lo%, or 100-I20 seconds per inch of depth. Flows therefore could vary between 450 and 550 gpm for the raceways and 675-825 for the Michigan ponds.

Flows were measured as well with a sonic flow meter. These flows were considerably different from the results obtained by meaasurement of filling rate for the raceways. However, the accuracy of the sonic flowmeter depends upon laminar flow of clean water through a completely filled pipe. Non-laminar flow due the presence of elbows in the pipe, particulates in the water, and partial filling of the inflow pipes may have resulted in the extreme variability in the measurements. For these reasons, we tended to have more confidence in the measurements of pond filling than in the use of the sonic flowmeter and have used the values presented in Table 2 for calculations.

Water temperatures were recorded on a Taylor thermograph. Precipitation was recorded by a National Oceanic and Atmospheric Administration weather observation station located at the hatchery.

Fish were fed BioMoist Feed from Bioproducts, Inc., Warrenton, OR. Feed was weighed daily for each pond and recorded with the cumulative amount of food per pond on a daily feed sheet. Fish growth was programmed to meet production goals based on historical monthly weight gains.

Mortalities of both tagged and untagged fish were enumerated and recorded weekly for each pond when the ponds were cleaned. Cumulative mortalities were used to estimate population sizes each month.

Sample counts to determine fish per pound for the single pass systems were taken at the end of each month by crowding the fish. Variable number of sample counts were taken by hatchery personnel on most months. Grab samples were obtained from the Michigan ponds. In September, December, and February, ten sample counts were performed for each raceway (Ewing et al. 1994), In the Michigan ponds, grab samples from various compartments were taken until ten sample counts were obtained.

Growth of the fish was calculated from pond counts from the equation

$$\text{Absolute Change} = w_2 - w_1 \tag{1}$$

where

w_2 = The average weight of fish at the end of the time period.

w_1 = The average weight of fish at the beginning of the time period.

Average weight of fish at each time period was multiplied by the total number of fish in the pond as estimated by pond inventories to give the total kg of fish in each experimental pond. These estimates may be somewhat greater than the actual biomass because **a** discrepancy in final biomass was found between estimates from pond inventories and those by liberation truck displacements. An unknown amount of bird and mammal predation was probably occuring during the rearing (Ewing and Sheahan, 1991, 1992).

Water Chemistry

Water samples were collected weekly during the rearing periods for chinook salmon for the four years of the study.

Samples were taken between 12:15 and 13:00, when initial feeding of the fish was completed and one exchange of water had taken place without the presence of human activities. The water samples were taken in the same order: inflow into Group E, outflow from Group E, outflow from Group F, outflow from Group G, outflow from Group D, outflow from Group C, outflow from Group A, outflow from Group B, inflow from an indoor rearing trough set up to record water temperatures.

The pH was measured at the sample site using an Orion pH meter model SA230 and an Orion combination pH electrode.

Ammonia analysis on the weekly samples was done using the phenate method (Clesceri et al. 1989). The samples and standards were read at 630 nm using a Milton Roy Spectronic 21 spectrophotometer. Ammonium concentrations in the inflow were subtracted from the concentrations determined at the effluent.

A Royce System VI instrument monitoring system was installed during the rearing season in 1992 to record the die1 changes in dissolved oxygen, temperature and pH. Dissolved oxygen probes were placed at the inflow and outflow of ponds designated A2, B2, C2, D2, El, Fl, Gl. Temperature information was also collected at the same locations. A pH probe was installed at the inflow of pond **C2** to determine the pH of incoming water for pond A2, B2, C2, and D2. One probe each was placed at the outflow of ponds A2, B2, C2, and D2. In the Michigan ponds (E, F, G) a **pH** probe was placed at the inflow of El, inflow of Fl, inflow of G1, and outflow of Gl. No differences were observed between the outflow of one pond and the inflow of the next pond in the series. Data was collected in 6 minute, 30 minute and 90 minute intervals and was stored as 48 hour samples, 10 day samples, and 30 days samples, respectively.

Die1 cycles of ammonia and urea production were measured on March 3-4, 1993, September 7-8, 1993, December 16-17, 1993, and February 27-28, 1994. Triplicate 5.0 ml samples were taken from the inflow and outflow of the experimental raceways at hourly intervals for a 30 hour period. Samples were capped, held at 4-6 C until sampling was complete, then transported to Biotech Research and Consulting in Corvallis, Oregon, for analysis.

Ammonium analysis on die1 cycles was performed by the phenylhypochlorite method of Zadojorny et al (1973). Ammonium concentrations in the inflow were subtracted from the concentrations determined at the effluent. Urea was measured by addition of urease to duplicate water samples 60 minutes before the analysis of ammonium concentrations. Urea concentration was determined as the difference between water samples with and without urease incubation. Urease contributed negligible ammonium to the water sample.

Nitrate and nitrite concentrations were determined for influent water and were found to be negligible. No sampling of effluent for nitrite or nitrate was undertaken, To determine ammonium and urea excretion rates, the fish were assumed to be randomly distributed throughout the volume of the pond. The concentration of the ammonium at the inflow given in Appendix B is assumed to-be the concentration in a 1 cm wide plane of water 6.1 m wide and 0.9 m deep. This plane sweeps through the 24.4 m length of the raceway, increasing in ammonium concentration from the excretion of the fish as the plane passes. The volume of this plane is 54,900 cubic centimeters or about 0.0549 m^3. Flow through the raceways is 500 gpm or 1.89 m^3/minute. Therefore, 34.4 of these planes form every minute and pass through the raceway at a velocity of about 20.6 m/hr. This equates to a turnover of about 1.18 per hr.

Using these calculations, the excretion of ammonium occurs at the rate dC/ds, where C is the ammonium concentration and s is the distance down the raceway. Because the fish are assumed to be uniformly distributed throughout the raceway, the biomass increases with distance down the raceway at the rate of dB/ds, where B is biomass in kilograms and s is distance down the raceway. The excretion can therefore be calculated as dC/dB. To obtain a rate of excretion, the velocity of the water must also be considered. Because the flow is considered for practical purposes to be constant at 500 gpm or 1.18 turnovers/hr, the ammonium excretion rate can be expressed as:

$$AER = (dC/dB)*1.18*60 \qquad (2)$$

This equation was used to calculate both circannual and die1 changes in ammonium excretion rates.

Changes in concentration were measured by subtracting ammonium levels of the effluent from those of incoming water (Appendix B). Changes in biomass were determined from estimates of populations by pond inventories and estimates of weight per fish from pond counts. Raw data for these calculations are shown in Appendix A.

Ammonium levels in Biomoist feed were determined by soaking 5.0 g samples of feed in 200 ml of distilled water. Ammonium was determined with time in 0.025 ml aliquots diluted to 5.0 ml with distilled water. Measurements were made either with swirling every 30 seconds or without swirling.

Proximate analyses of feed samples and fish were performed by standard methods from the Journal of the Association of Official Analytic Chemists. Protein was determined by the method of Lowry et al. (1951). Fat was determined gravimetrically after extraction of lipids with chloroform/methanol (3/l, v/v). Water content was determined from the difference between wet weights **and** weights after drying for 24 hours at 105 C. Ash weight was determined after heating a known dry weight of material to 550 C for four hours.

Statistical analyses were performed according to Zar (1984). Analysis of variance, analysis of covariance, and Student's t tests were performed when required. Linear regression analysis was used when appropriate. All tests were performed at the 95% confidence level.

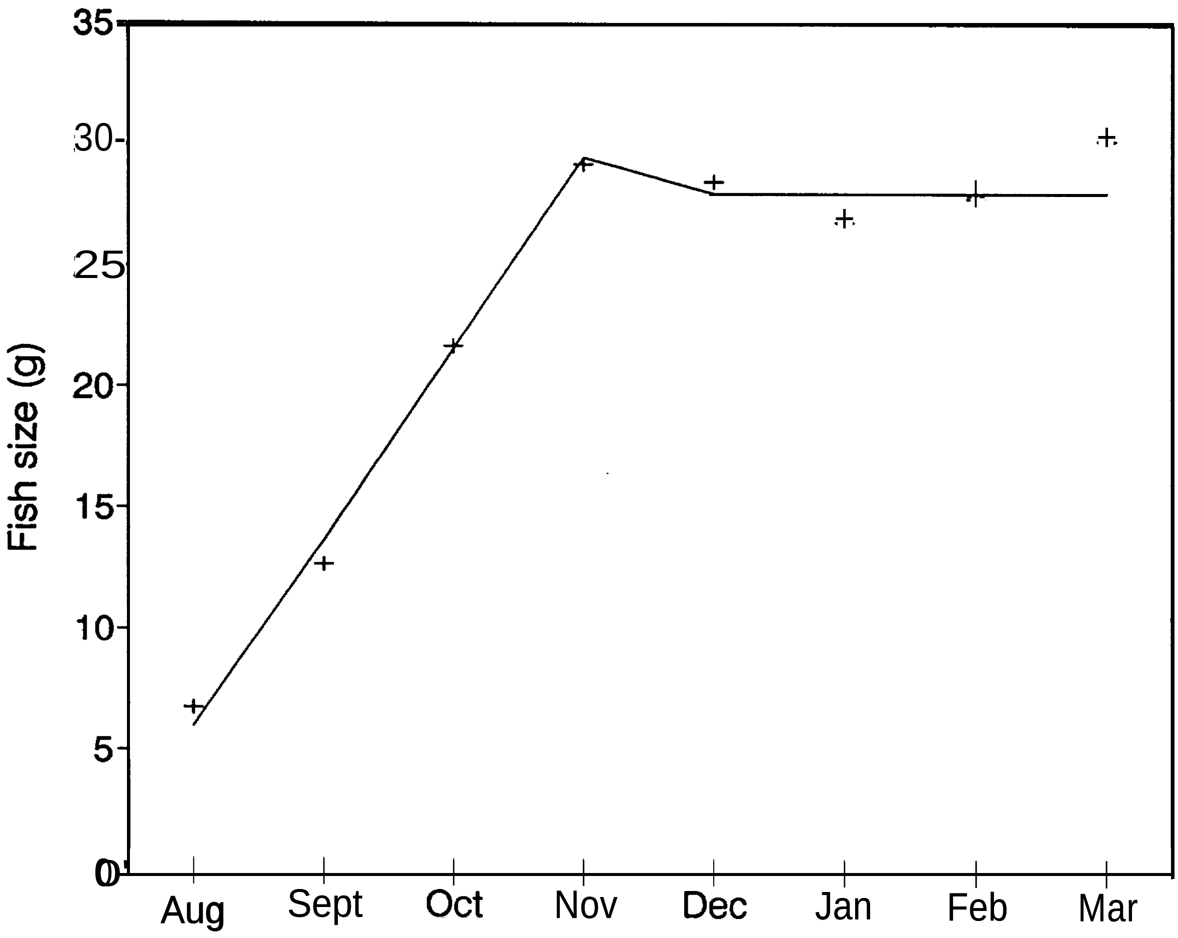
RESULTS AND DISCUSSION

Analysis of Growth Rates

Calculation of the nitrogen excretion rate from a pond of fish requires a knowledge of the biomass of the fish within the pond. From previous experiments, an error of at least 5% was expected for each measurment of fish size at Willamette Hatchery (Ewing et al. 1994). This variation caused an irregular apparent growth rate where the average size of fish at a particular month was often smaller than that of the previous month. Because of this variation, it was deemed more efficient to use regression analysis of size estimates and calendar day to determine growth rates. The equation for this relationship could then be used to determine the biomass of fish in a pond at any particular date.

Estimates of fish size were made monthly throughout the rearing period from July to March. Raw data for such estimates (Appendix A) were derived from pond inventory sheets and from previous reports. An example of the growth curve obtained from these estimates is shown in Fig. 1. Growth curves formed biphasic relationships, where growth increased linearly until October or November when growth either ceased or continued to increase at a very slow rate (Fig 1). Correlation coefficients of relationships between estimated size and calendar day transformed to a rectangular hyperbola were never as high as those obtained from the assumption of a biphasic relationship.

Figure 1. Change in size (g) of juvenile chinook reared in experimental group A2 at Willamette Hatchery, 1993-1994.


Fish size (g)
35
30
25
20
15
10
5
0
Aug
Sept
Oct
Nov
Dec
Jan
Feb
Mar

The end point of rapid growth varied from year to year and group to group, so it was necessary to examine each curve before performing regressions. The end point of rapid growth usually occurred either in October or November when the water temperature cooled below 5°C. Growth rates were therefore obtained from regressions from August to October or November and from October or November until release. These were expressed as total kg/pond/day (Table 3). These rates were then used to calculate the number of kg of fish present in the raceways at any given time.

Growth relationships between experimental groups of fish will be analyzed more thoroughly in future annual reports.

Analysis of Ammonia Excretion

Ammonium Ions in the Feed

Before true excretion rates could be determined for chinook salmon, the extent to which ammonium ions were introduced into the raceway effluent from the feed was determined. A series of experiments were performed to determine the amount of ammonium ion in BioMoist Feed and the rate at which it was liberated into the medium.

Soaking the feed in water released a yellowish color which interfered with the development of the phenylhypochlorite reaction. The absorbtion maximum for an extract of the feed in water was determined to be 298 nm. In order to determine the

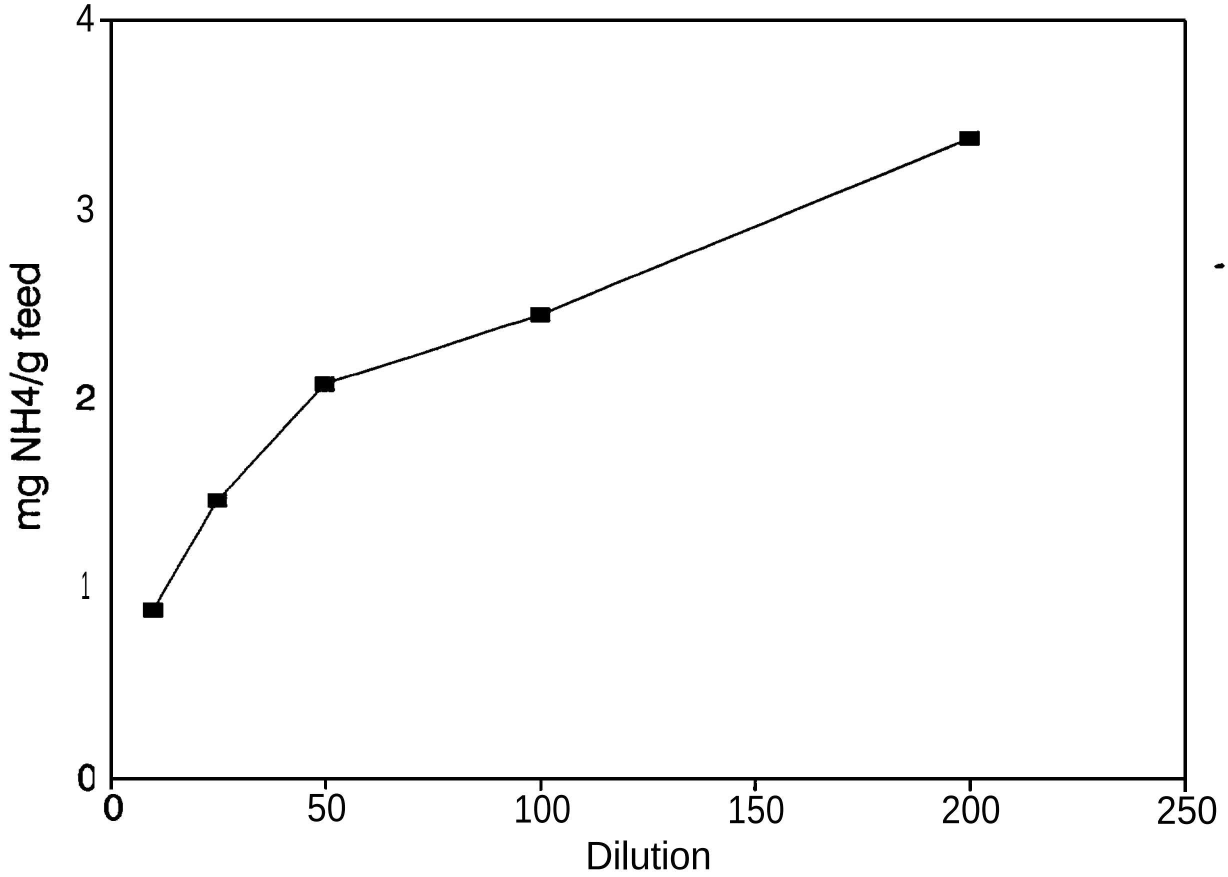
Table 3. Increase in biomass per raceway (kg/day) for experimental raceways of chinook salmon estimated by linear regression of biphasic growth curves. Raw data for growth estimates are included in Appendix A.

Year, group	Aug-->Nov			Nov-->Mar		
	Slope	Intercept	R^2	Slope	Intercept	R2
1990-1991						
Al	13.54	-2675.0	0.794	2.01	719.8	0.757
Bl	7.58	-1486.9	0.803	2.41	-33.0	0.648
Cl	12.47	-2410.3	0.861	2.79	401.8	0.816
Dl	32.19	-6291.2	0.873	1.96	2875.5	0.336
El	12.94	-2399.9	0.899	1.64	950.8	0.635
Fl	16.58	-3181.9	0.865	0.40	1726.6	0.030
Gl	18.75	-3799.3	0.847	0.26	1712.7	0.045
A2	12.00	-2300.2	0.983	1.01	1038.9	0.359
B2	5.83	-1074.5	0.871	1.00	391.5	0.729
c2	11.64	-2226.0	0.893	2.65	483.9	0.692
D2	30.44	-5479.7	0.831	3.58	2773.8	0.194
E2	22.55	-4822.0	0.971	-2.04	2499.1	0.291
F2	17.52	-3432.9	0.860	0.36	1793.0	0.021
G2	18.22	-3642.4	0.850	1.30	1393.2	0.457
1991-1992						
Al	12.12	-2302.2	0.992	1.99	819.9	0.878
Bl	5.88	-1085.6	0.9996	2.07	105.2	0.849
Cl	10.85	-2055.8	0.984	3.20	344.9	0.849
Dl	28.57	-5391.3	0.993	6.38	1486.5	0.784
El	11.04	-1832.6	0.963	0.30	1648.0	0.005
Fl	12.40	-2160.5	0.985	3.08	742.9	0.837
Gl	13.47	-2464.2	0.990	2.61	877.3	0.841
A2	10.26	-1839.6	0.990	3.59	165.4	0.862
B2	5.62	-1030.3	0.990	1.10	351.6	0.527
c2	9.69	-1805.8	0.968	2.91	294.3	0.869
D2	23.99	-4334.6	0.989	7.86	661.4	0.878
E2	8.81	-1354.7	0.993	3.33	353.3	0.801
F2	10.82	-1805.8	0.959	4.56	193.2	0.806
G2	12.30	-2154.7	0.981	2.66	1033.1	0.390

Table 3. (cont.)

Year, group	Aug-->Nov Slope	Intercept	R^2	Nov-->Mar Slope	Intercept	R2
1992-1993						
Al	12.51	-2253.9	0.975	2.94	635.3	0.903
Bl	6.22	-1099.4	0.994	1.20	430.6	0.671
Cl	11.84	-2122.5	0.962	4.09	212.9	0.899
Dl	34.05	-5972.2	0.986	6.23	2615.5	0.483
El	17.39	-3087.1	0.952	-1.48	2736.1	0.415
Fl	13.66	-2272.0	0.988	2.48	1249.2	0.480
Gl	16.65	-3019.3	0.9998	0.89	1880.8	0.074
A2	7.62	-1163.7	0.866	3.80	-176.4	0.787
B2	4.99	- 818.6	0.940	2.26	-20.6	0.952
c2	12.06	-2118.7	0.985	3.60	398.2	0.838
D2	33.33	-5835.0	0 9 9 8	5.47	2705.7	0.892
E2	14.60	-2545.2	0.992	-0.51	2148.6	0.101
F2	15.04	-2643.1	0.978	2.45	1269.3	0.347
G2	14.39	-2474.6	0.989	2.70	1200.8	0.562
1993-1994						
Al	8.03	-1474.5	0.988	1.65	429.3	0.601
Bl	4.74	- 901.9	0.983	1.15	185.5	0.962
Cl	9.59	-1855.0	0.973	1.52	608.5	0.502
Dl	24.52	-4740.2	0.968	3.38	1681.4	0.569
El	9.60	-1702.0	0.990	-2.42	2058.9	0.589
Fl	12.01	-2198.9	0.993	-1.35	1987.8	0.230
Gl	10.76	-1981.1	0.986	2.11	656.0	0.413
A2	9.81	-1855.5	0.993	-0.42	1259.1	0.311
B2	6.35	-1266.6	0.939	0.88	267.1	0.829
c2	8.84	-1646.3	0.971	0.90	770.9	0.337
D2	27.04	-5183.4	0.987	0.20	3035.5	0.006
E2	10.24	-1798.1	0.986	3.33	219.0	0.611
F2	11.22	-2028.2	0.973	2.85	457.1	0.398
G2	10.97	-2037.0	0.984	2.01	676.6	0.741

Figure 2. Estimated ammonium content of BioMoist Feed as a function of dilution of the extract.



mg NH4/g feed
Dilution
0
1
2
3
4
0
50
100
150
200
250

amount of ammonium ion, it was necessary to dilute the extract by varying amounts (Fig. 2). Because the concentration of inhibitor was also diluted, the most accurate values were those that could be diluted to the greatest extent without loss in accuracy of the spectrophotometer readings. The dilution used in most cases where the feed was stirred was l/200 dilution. Using this dilution, the .-level of ammonium ion in feed was about 3.37 $\pm$ 0.27 mg/g feed or about 0.34%.

If the water containing the feed was agitated, the release of NH4 into the water followed a nonlinear curve (Fig 3). This probably resulted from the swelling and loss of integrity of the pellets with time of stirring. Initially, ammonium ion was released rapidly, but the rate decreased with time as smaller and smaller particles became fragile and released their ammonium. The relationship was best described by the equation

$$l/(\text{mg } NH_4/\text{g food}) = -0.61873\ (\ln\ (\text{time in minutes})) + 0.914 \quad (3)$$

which had an R^2 of 0.947 (Fig. 4).

If the water containing the food was not stirred, the rate of release followed a biphasic line (Fig. 5). In the unstirred samples, the pellets immediately released ammonium ions from the surface, then swelled upon soaking with water. The swelling liberated more ammonium, but the rate of liberation was limited by diffusion. Therefore, after an initial release of ammonium, the rate of liberation became linear. The relationship between time and ammonium release could be described by two equations:

Figure 3. Release of ammonium ions from BioMoist Feed with time when the sample was stirred.

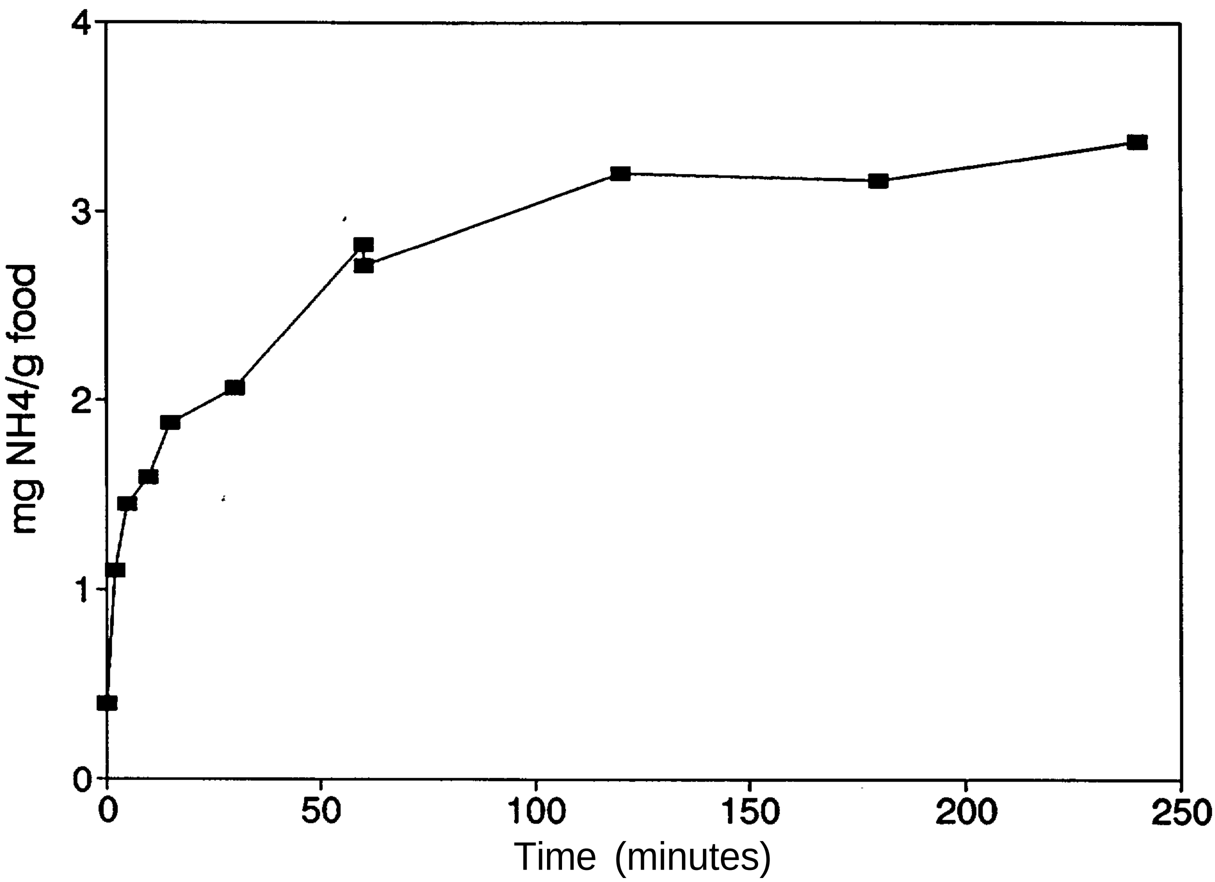
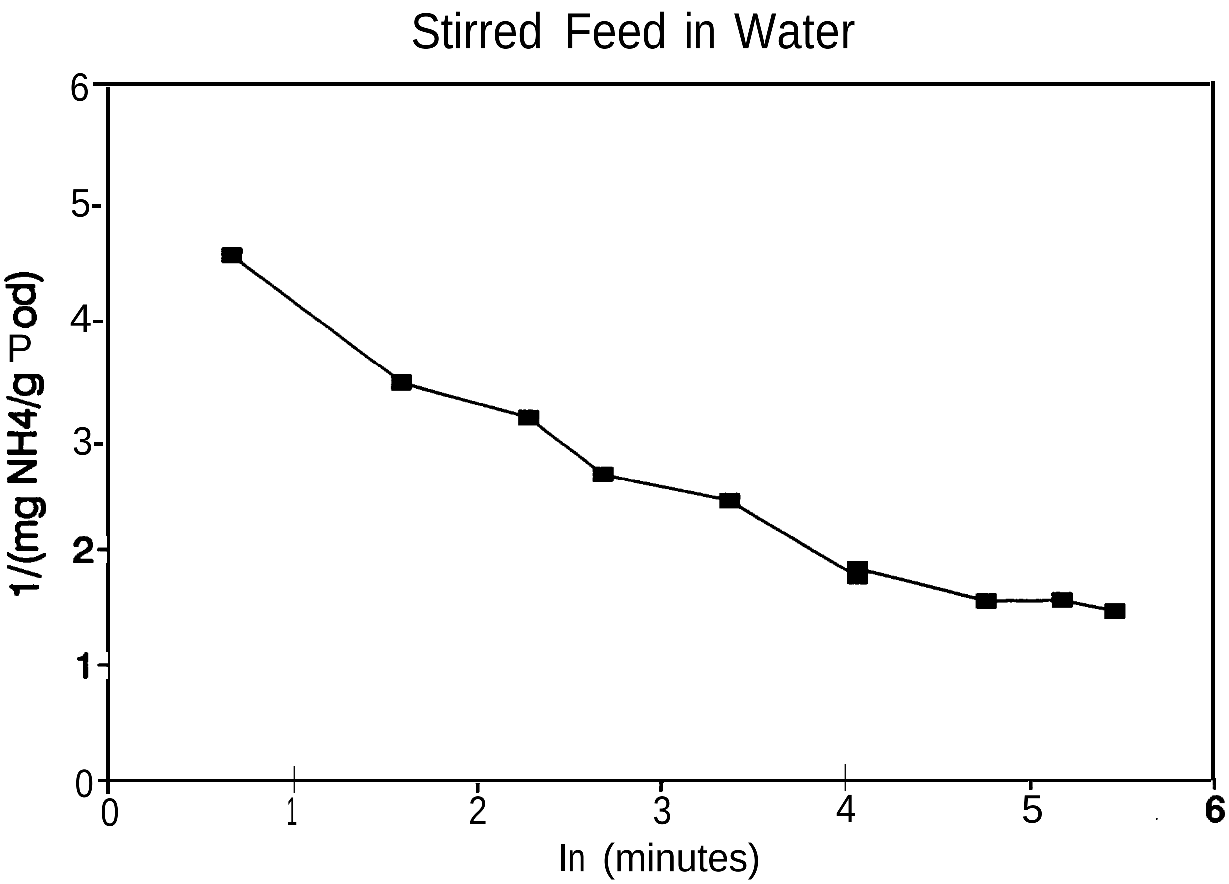
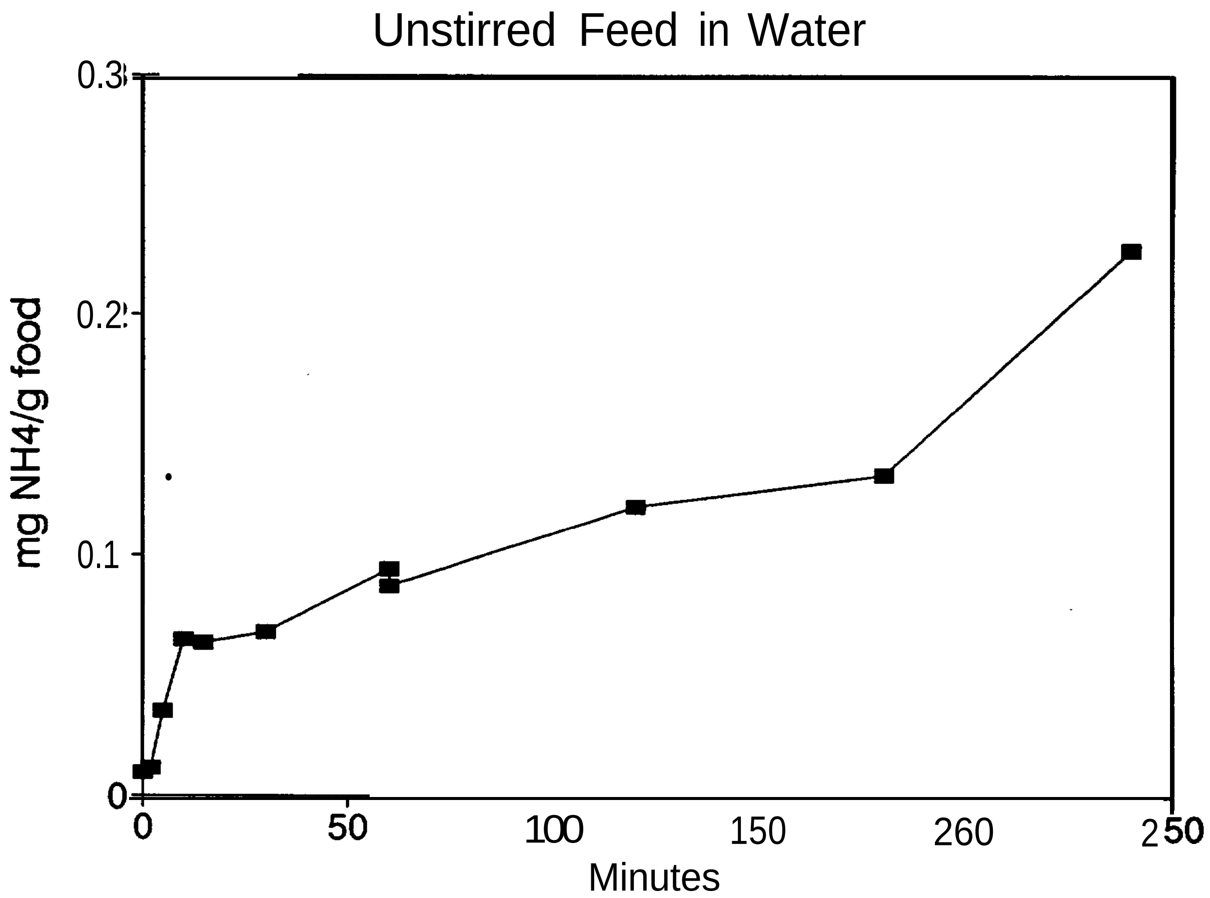

4
3
2
1
0
mg NH4/g food
0
50
100
150
200
250
Time (minutes)

Figure 4. Relationship between the natural log of the time of stirring in minutes and the reciprocal of the mg NH_4 released per gram of BioMoist Feed.



Stirred Feed in Water
1/(mg NH4/g Pod)
ln (minutes)
0
1
2
3
4
5
6

Figure 5. Release of ammonium ions from BioMoist Feed with time when the sample was not stirred.



Unstirred Feed in Water
0.3
0.2
0.1
0
mg NH4/g food
0
50
100
150
260
250
Minutes

$$\text{mg NH4/g food} = 0.0053\ (\text{minutes}) + 0.0063 \qquad R2 = 0.876 \qquad (4)$$

$$\text{mg NH4/g food} = 0.00066\ (\text{minutes}) + 0.0469 \qquad R^2 = 0.980 \qquad (5)$$

for the time interval from 0 to 5 minutes and from 5 to 240 minutes, respectively.

With these equations, it was possible to estimate the amount of ammonium introduced into the raceway during the feeding process. However, a number of assumptions were required at this point, because we have no information on the extent to which the food is eaten and the rate at which the pellets are broken up in the raceway. It seemed reasonable from the hydraulics of raceways and Michigan ponds that the pellets were fragmented at a slower rate in the raceways than in the Michigan ponds. This could be observed directly in the ponds after feeding. Uneaten food could be seen on the bottom of raceways as intact pellets, while uneaten food could rarely be seen on the bottom after passing under several baffles in the Michigan ponds. It was therefore assumed that the rates of ammonium ion release in the Michigan ponds approximated the rate of stirred samples, while the rate of release in raceways approximated that from the unstirred samples.

Other assumptions were: 1) Ammonium levels do not vary appreciably between bags of feed. 2) The fish are fed once every two hours during the working day, or 5 times a day. 3) This procedure varies throughout the rearing season, depending on temperature, until winter when the fish are fed only twice a day at reduced levels. 4) The amount of feed fed to the fish was divided evenly between feedings. 5) That the amount of feed eaten was 90%. 6) The time elapsed between feeding the fish and their consumption of the food was about 10 seconds. 7) The percent of feed eaten did not vary between feedings or'months. The amount of feed fed to each pond was available through feeding charts at the hatchery and is presented in Appendix D.

Each of the assumptions has some variability associated with the number used. The number of feedings during warmer months depended upon the number of personnel available for feeding duty. The number varied from 3 to 8, although the number was biased toward the upper end. Five feedings per day was a reasonable estimate in late summer and early fall because, during the growing months, the fish were reared as fast as possible. In winter, feedings varied from 0 to 2, depending on conditions. If the water was muddy, the fish were not fed because they would not eat and the feed was wasted.

Assumption 4 is probably fairly sound. The number of kilograms of fish was followed monthly and the amount of feed to be fed was calculated ahead of time at 2-3% of body weight. Consequently, it was possible to weigh out equal portions of the feed to be fed during the day to reach the daily feed goal.

Assumptions 5 and 6 are merely guesses. Fish were watched during the feeding process to ensure that they were eating the feed. When they reached satiation, feeding was halted. Satiation was determined by the reduced activity of the fish and the appearance of uneaten food pellets on the bottom of the raceway. The assumption is that these pellets represented 5-10% of the total feed. This amount probably varies with the perception of the feeder. The time required to consume the food once it is introduced can be measured in seconds. Fish usually swarmed about the area of feeding and rapidly consumed any particles that appear. The speed at which they consumed the pellets probably varied with season and water temperature but no definite measurements were available.

Assumption 7 is again a guess. It was assumed that between feedings the fish again became hungry enough to eat the next portion of feed and the process described under assumption 4 occurred repeatedly during the day.

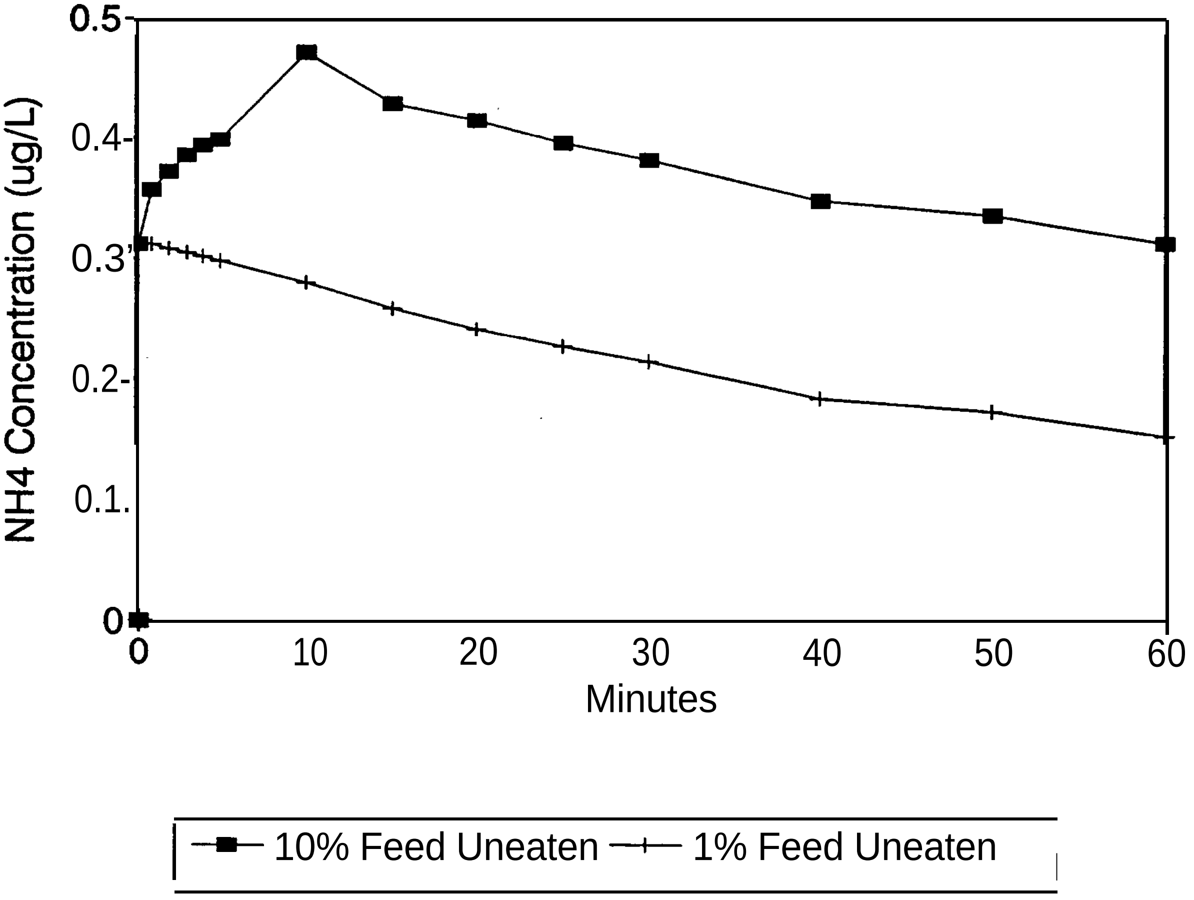
By making the above assumptions, it was possible to calculate the amount of ammonium ion introduced into the raceways each day during feeding. This amount was calculated in the following way: If 50 pounds of food are fed to a raceway on a particular day, then 10 pounds of food are fed at each feeding. The total amount of ammonium in the feed at each feeding is equal to 0.0034 x 10 x 454 or 15.44 g. This is released upon feeding according to equations 7 and 8, such that mg NH_4/g feed produced in the first 10 seconds is (0.0053 x 0.17) + 0.0063 or 0.0072 mg/g feed. There are 10 x 454 or 4540 g of feed fed during the feeding, so this results in 0.0072 x 4540 or 32.7 mg of NH4 released in the first 10 seconds. After this time, 90% of the feed is consumed and no longer releases ammonium (except inside the fish). The remaining 10% or 454 g feed continues to release ammonium. In the raceways, this will release 0.0053 x 5 + 0.0063 or 0.033 mg/g in the first 5 minutes and at a rate of 0.00066 mg/g/minute thereafter. For 454 g of feed, this is equivalent to 15.0 mg in the first five minutes and 0.3 mg/minute for the time after that.

Total volume of each raceway is approximately 3700 cu ft or 104,769 L. It is assumed that the feed is evenly distributed, so in the first 10 seconds, 32.7 mg of NH_4 is distributed throughout 104,769 L to give a concentration throughout the raceway of 0.31 ug/L. Flow in the raceway is 500 gpm or 1895 Lpm. It takes 55.29 minutes to flush the raceway completely, so turnover in the raceway is 0.92/hour. Ammonium from the food is being discharged from the raceway at a rate of 0.31 ug/L x 1895 L/min or 0.59 mg/min during the first minute. In five minutes, the feed has discharged 46.6 mg NH_4 while losing 5.8 mg NH_4 in the effluent. Total NH_4 content in the raceway is therefore (47.6 - 5.9) or 41.8 mg NH_4. This would provide a concentration of 0.40 ug/L. Changes in ammonium concentration in the raceway would subsequently follow the curve shown in Fig. 6. A maximum level would be reached in 10 minutes, then the concentration would slowly decrease with time. For comparison, a second time course of ammonium concentration is shown that assumed that only 1% of the food remained after 10 seconds. In the latter case, the concentration in the raceway reached a maximum after 10 seconds, then slowly decreased as the ammonium was swept from the pond.

How well do these calculations conform with reality? The assumption of 10 lbs (4.54 kg) of feed per feeding is reasonable for the ponds with high densities during the warmer months

Figure 6. Ammonium concentration (ug/ml) in raceways with time after feeding of 10 pounds of BioMoist feed, assuming that 10% (-■-) and 1% (-+-) of the food remained uneaten.

NH4 Released from Feed

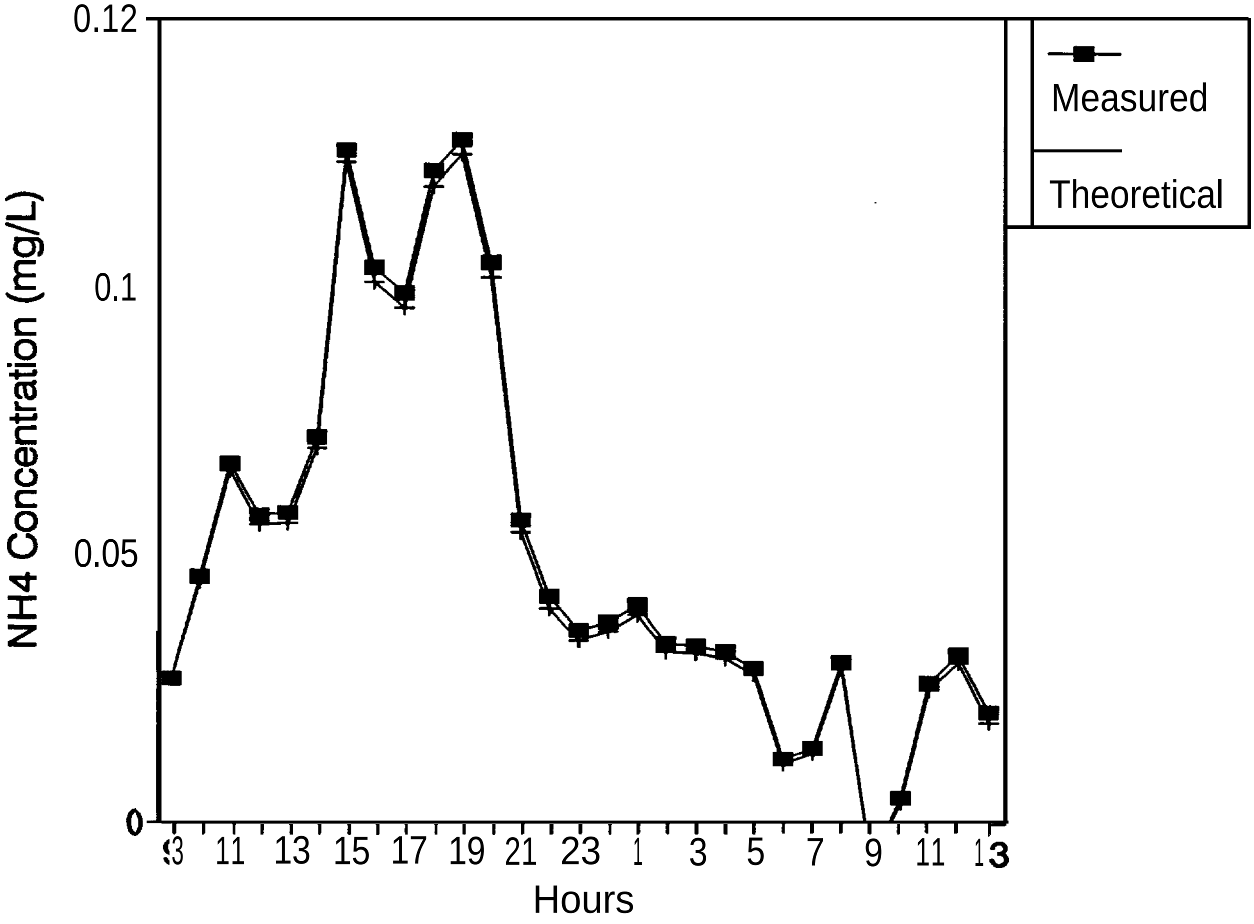


(Appendix D). The concentrations of ammonium contributed by the feed, however, is quite low compared to that from excretion from the fish. A simulation was made for ammonium contribution from feed on September 7-8, 1993, during sampling for die1 changes in ammonium output from group A. Ammonium excretion at this time was cyclic, the fish were growing rapidly, and large amounts of feed were fed each day. Ammonium ions contributed from the feed (calculated as above) were subtracted from the measured ammonium concentrations at the outlet of group A. As indicated in Fig. 7., the contribution of ammonium ions from the feed was negligible compared to the excretion by the fish. A similar simulation was performed for group D (high rearing density) with similar results. From these calculations, it was concluded that a correction of measured ammonium levels in raceways for the amount contributed by the feed was unnecessary.

Circannual Changes in Ammonia Excretion Rate (AER)

The phenylhypochlorite method for detection of ammonia in water measures the concentration of ionized ammonia, referred to from here on as ammonium. Ammonia, or unionized ammonia, will be used only to refer to the gas. This distinction was not clearly made in our first four annual reports (Ewing and Sheahan 1991, 1992; Ewing et al. 1993, 1994). In the tables in those reports, ammonium concentrations in the raceways were referred to as "unionized ammonia" concentrations. As shown in a later section

Figure 7. Measured ammonium concentrations (ug/ml) in the effluent from group A on September 7-8, 1993. Theoretical effluent concentrations are shown for comparison, where the ammonium ions contributed by the feed are subtracted.



NH4 Concentration (mg/L)
0.12
0.1
0.05
0
9
11
13
15
17
19
21
23
1
3
5
7
9
11
13
Hours
Measured
Theoretical

of this report, these concentrations are from 100 to 400-fold higher than the estimated ammonia concentrations. "Ammonia" concentrations from previous annual reports are reproduced with the appropriate heading in Appendix B.

Weekly sampling of water from inflows and outflows of experimental ponds provided a means of determining the circannual changes in ammonium ion excretion from fish in experimental ponds. Changes in ammonium ion concentration at the outflows of raceways containing groups A, B, and D are shown for the four rearing years (Fig. 8). Changes in ammonium ion concentrations at the outflows of raceways in the Michigan pond series (groups E, F, and G) are also shown for the four rearing years (Fig. 9).

In general, ammonium production in all raceways decreased with time. Ponds with the greatest rearing densities produced the highest ammonium ion concentrations in the effluent. In the Michigan series, ammonium concentration increased as the water was recycled through the lower ponds, so that fish in group F were reared in higher ammonium concentrations than those group E and fish in group G were reared in higher ammonium concentrations than those in group F.

In order to compare changes in ammonium excretion rates during the rearing periods, it was necessary to compensate for the changes in biomass in the raceways with time and the flow of water through the raceways. The original data presented in Appendix B was recalculated as mg NH4/hr/kg fish. To make these calculations, flow was considered to be constant at the levels shown in Table 2. The amount of ammonium ion produced per hour

Figure 8. Ammonium concentrations (mg/L) at the effluent of raceways containing experimental groups A, B, and D for four rearing years at Willamette Hatchery.

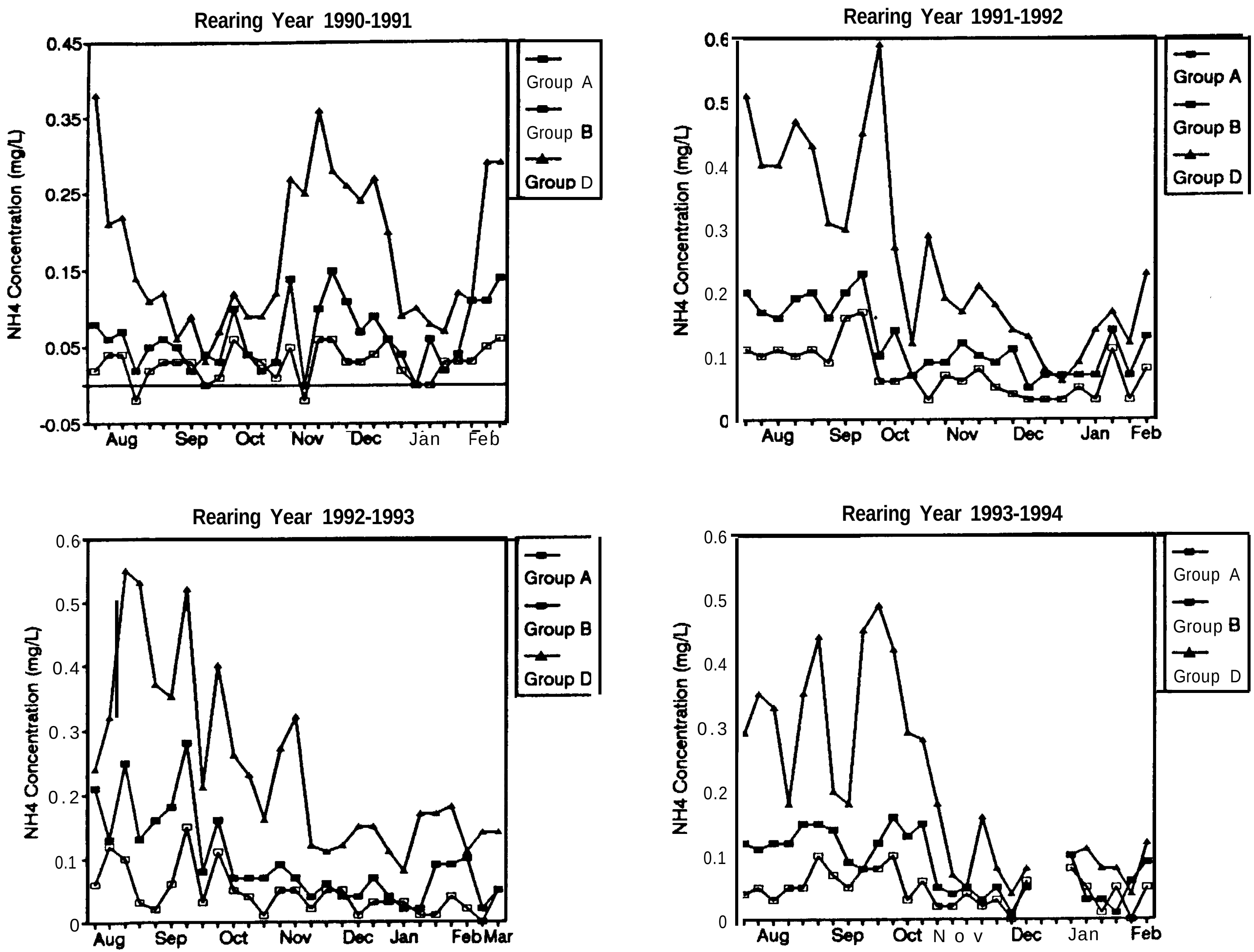
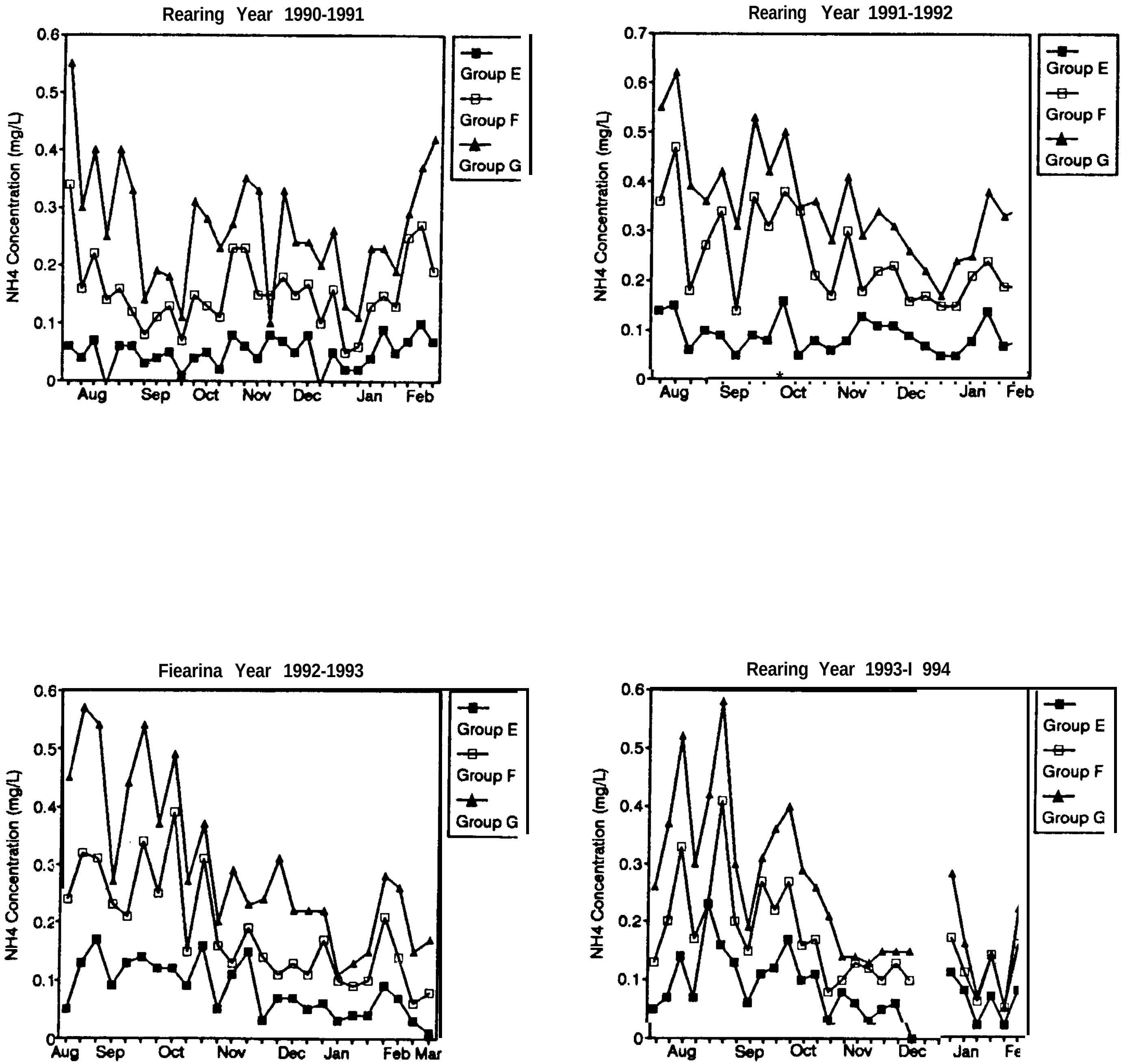

Rearing Year 1990-1991
NH4 Concentration (mg/L)
0.45
0.35
0.25
0.15
0.05
-0.05
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Group A
Group B
Group D
Rearing Year 1991-1992
NH4 Concentration (mg/L)
0.6
0.5
0.4
0.3
0.2
0.1
0
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Group A
Group B
Group D
Rearing Year 1992-1993
NH4 Concentration (mg/L)
0.6
0.5
0.4
0.3
0.2
0.1
0
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Group A
Group B
Group D
Rearing Year 1993-1994
NH4 Concentration (mg/L)
0.6
0.5
0.4
0.3
0.2
0.1
0
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Group A
Group B
Group D

Figure 9. Ammonium concentrations (mg/L) at the effluent of raceways containing experimental groups E, F, and G for four rearing years at Willamette Hatchery.

Fig 9


Rearing Year 1990-1991
Rearing Year 1991-1992
Fiearina Year 1992-1993
Rearing Year 1993-I 994
NH4 Concentration (mg/L)
Group E
Group F
Group G
Aug Sep Oct Nov Dec Jan Feb Mar

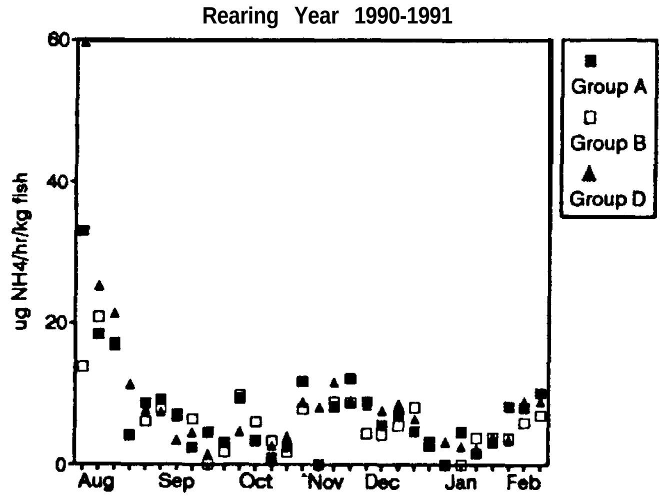
was calculated using the assumption that the samples provided in Appendix B were representative of a plane of water exiting from the experimental raceways and that the ammonium ion was distributed randomly within the plane. Kilograms of fish at each time of ammonium measurement was determined by applying the regression equations shown in Table 3.

Changes in ammonium excretion rates (mg NH4/hr/kg fish) (AERs) for raceways (Fig. 10) were somewhat lower than those for Michigan ponds (Fig 11) but these relationships were hard to quantify in their non-linear state. AERs were transformed to provide linear relationships with calendar day for linear regression analysis. The best fit was obtained for the relationship between calendar day and In (AER) (Fig 12). Slopes and intercepts for these relationships for the four years of the experiment are shown in Table 4.

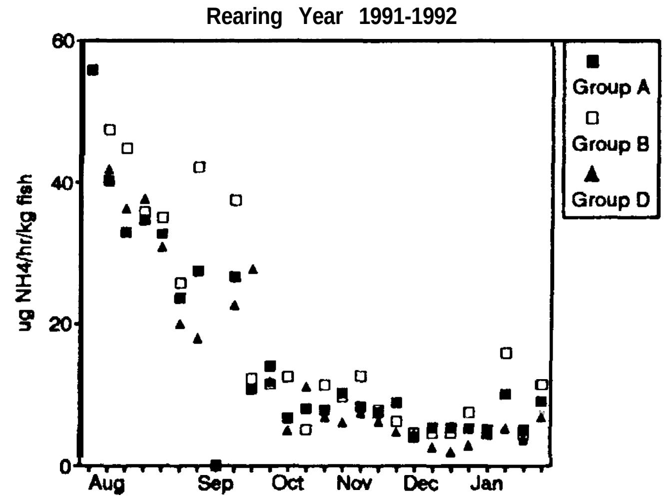
During the first year of rearing in 1990-1991, the relationship between AER and calendar day was not significant in five of the seven raceways measured. Also, slopes were all significantly lower than in the following years. This was probably due to problems with the development of the ammonium assay during the first year of sampling. The data should therefore be considered suspect in further analyses.

The decreases in AER observed with calendar day could be due either to decreases in water temperature, which became cooler as winter approached, to increased size of the fish with time, or to decreased photoperiod. These relationships were examined further.

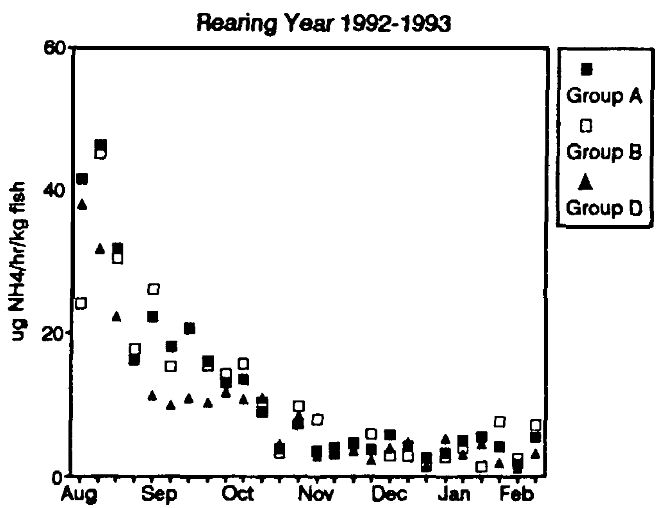
Figure 10. Changes in AER with calendar day for raceways containing fish from groups A, B, and D for four rearing years at Willamette Hatchery.



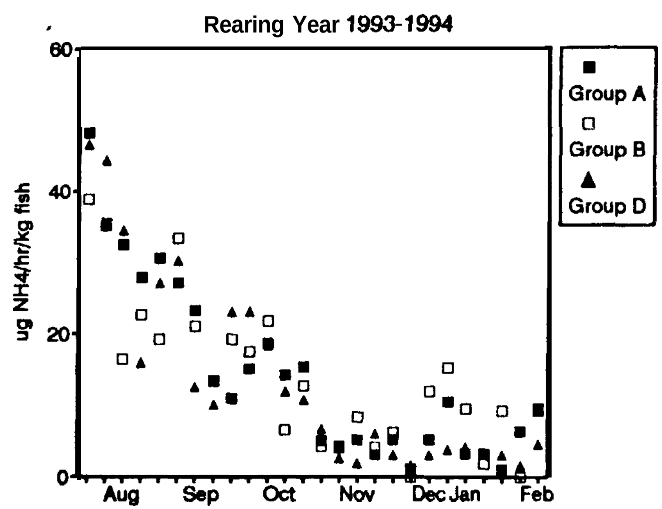
Rearing Year 1990-1991
ug NH4/hr/kg fish
60
40
20
0
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Group A
Group B
Group D



Rearing Year 1991-1992
ug NH4/hr/kg fish
60
40
20
0
Aug
Sep
Oct
Nov
Dec
Jan
Group A
Group B
Group D



Rearing Year 1992-1993
ug NH4/hr/kg fish
60
40
20
0
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Group A
Group B
Group D



Rearing Year 1993-1994
ug NH4/hr/kg fish
60
40
20
0
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Group A
Group B
Group D

Figure 11. Changes in AER with calendar day for raceways containing fish from groups E, F, and G for four rearing years at Willamette Hatchery.

Figure 12. Relationship between calendar day and In (AER) for group A during rearing year 1993-1994 at Willamette Hatchery.

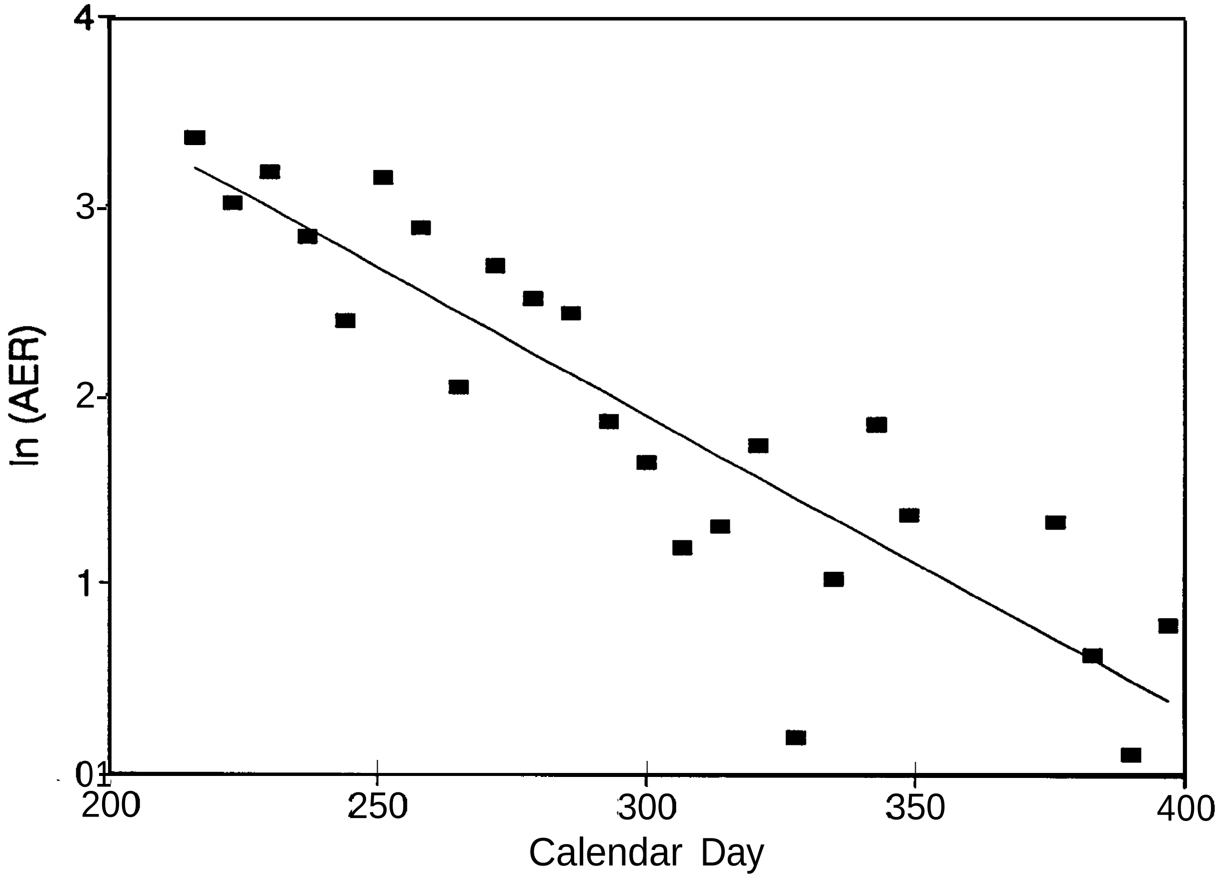

4
3
2
1
0
ln (AER)
200
250
300
350
400
Calendar Day

Table 4. Regression analysis for the relationship between calendar day and ln (ammonium excretion rate). Values represent data from August to March of each rearing year. *, not significant at the 95% confidence level.

Year, group	Slope	Intercept	R2	N
1990-1991				
A1	-0.0034	2.847	0.071*	28
B1	-0.0045	2.189	0.197*	25
C1	-0.0049	3.175	0.141*	30
D1	-0.0050	3.383	0.144*	30
E1	-0.0037	3.067	0.121*	28
F1	-0.0094	5.634	0.429	29
G1	-0.0090	5.425	0.414	29
1991-1992				
A1	-0.0106	5.713	0.681	25
B1	-0.0100	5.554	0.681	25
C1	-0.0135	6.590	0.718	25
D1	-0.0122	5.930	0.717	25
E1	-0.0093	5.318	0.681	25
F1	-0.0125	6.853	0.813	25
G1	-0.0089	5.672	0.528	25
A2	-0.0115	6.084	0.758	25
B2	-0.0122	6.407	0.681	25
C2	-0.0147	6.887	0.746	24
D2	-0.0151	6.995	0.809	25
E2	-0.0065	4.555	0.460	25
F2	-0.0161	8.083	0.821	23
G2	-0.0095	5.398	0.359	24

Table 4. (cont.)

Year, group	Slope	Intercept	R2	N
1992-1993				
Al	-0.0135	6.236	0.698	27
Bl	-0.0113	5.414	0.499	26
Cl	-0.0114	5.415	0.634	27
Dl	-0.0113	5.485	0.767	27
El	-0.0103	5.230	0.634	25
Fl	-0.0100	5.398	0.516	25
Gl	-0.0099	5.396	0.401	25
A2	-0.0015	6.322	0.755	26
B2	-0.0135	6.426	0.678	26
c2	-0.0097	4.767	0.657	25
D2	-0.0135	6.185	0.770	26
E2	-0.0113	5.957	0.711	27
F2	-0.0120	6.111	0.773	27
G2	-0.0105	5.587	0.545	27
1993-1994				
Al	-0.0135	6.630	0.658	26
Bl	-0.0131	6.554	0.674	23
Cl	-0.0130	5.862	0.570	22
Dl	-0.0148	6.357	0.785	24
El	-0.0116	5.940	0.657	26
Fl	-0.0134	6.736	0.666	25
Gl	-0.0127	6.410	0.498	25
A2	-0.0136	6.457	0.608	26
B2	-0.0086	5.100	0.439	24
c2	-0.0130	6.093	0.660	25
D2	-0.0156	6.919	0.732	26
E2	-0.0106	5.770	0.582	25
F2	-0.0116	6.048	0.636	25
G2	-0.0167	7.489	0.556	24

Effect of Water Temperature on Ammonium Excretion Rate

Water temperatures decreased seasonally during the four experimental rearing years (Fig 13). Ammonium excretion rates (AERs) decreased with falling temperatures but the decreases were not linear (Fig. 14). The best fit for regressions of water temperature vs AER was obtained if Arrhenius plots were used (Fig. 15). Arrhenius (1889) proposed that temperature influences chemical and biological reactions according to the relationship $d(\ln k)/dT = A/RT^2$, where k is the reaction velocity, T is the temperature in degrees Kelvin, R is the gas constant (1.987 Cal/degree/mole) and A is a constant. When integrated and rearranged, the Arrhenius equation is

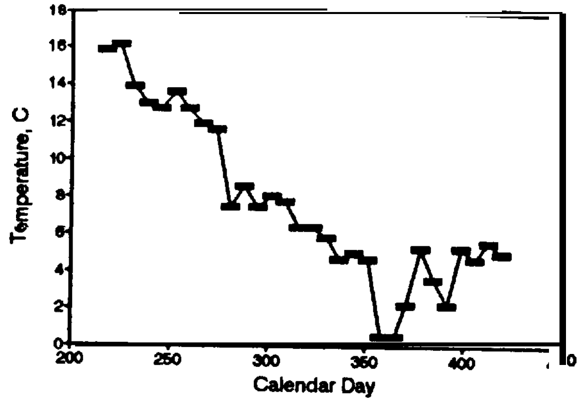
$$\ln k = -A/RT + \ln C \qquad (6)$$

where C is a second constant. This equation describes the influence of temperature on a variety of physiological process from the reaction of molecules in a test tube to the chirping of crickets. Temperatures and AERs for individual groups were transformed for use in the Arrhenius equations and the relationships were subjected to linear regression analysis. Slopes and intercepts obtained from linear regression of In (AER) against l/T are shown in Table 5.

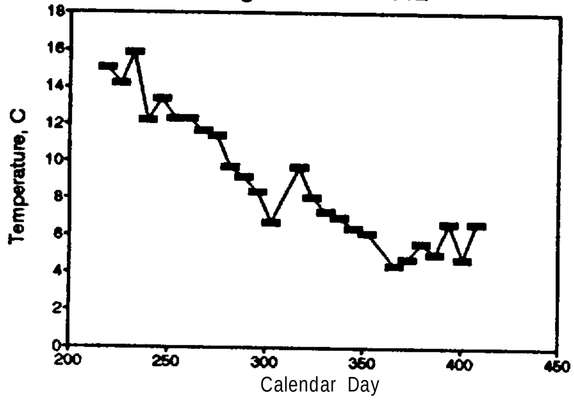
Analysis of covariance was performed to test whether slopes of Arrhenius plots derived from each experimental pond were different within rearing years. No significant differences in slopes were determined for rearing years 1990-1991, 1992-1993,

Figure 13. Water temperatures at the inflow of experimental raceways for rearing years at Willamette Hatchery. A. 1990-1991 rearing period. B. 1991-1992 rearing period. C. 1992-1993 rearing period. D. 1993-1994 rearing period.

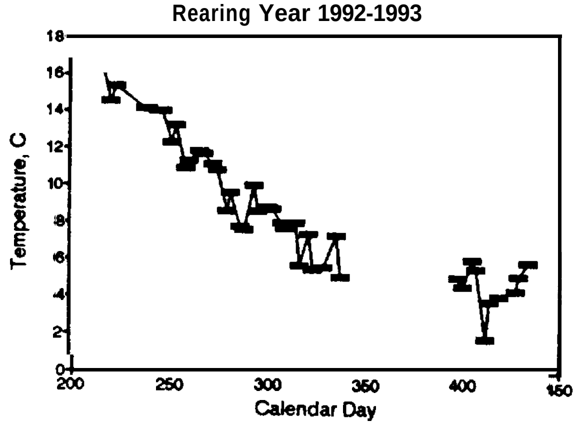
Rearing Year 1990-1991



Rearing Year 1991-1992



Rearing Year 1992-1993



Rearing Year 1993-1994

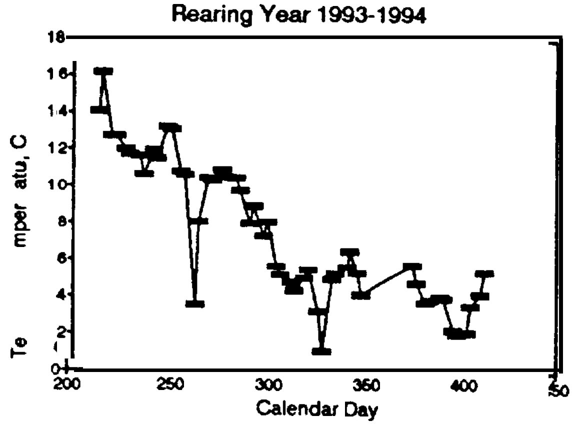
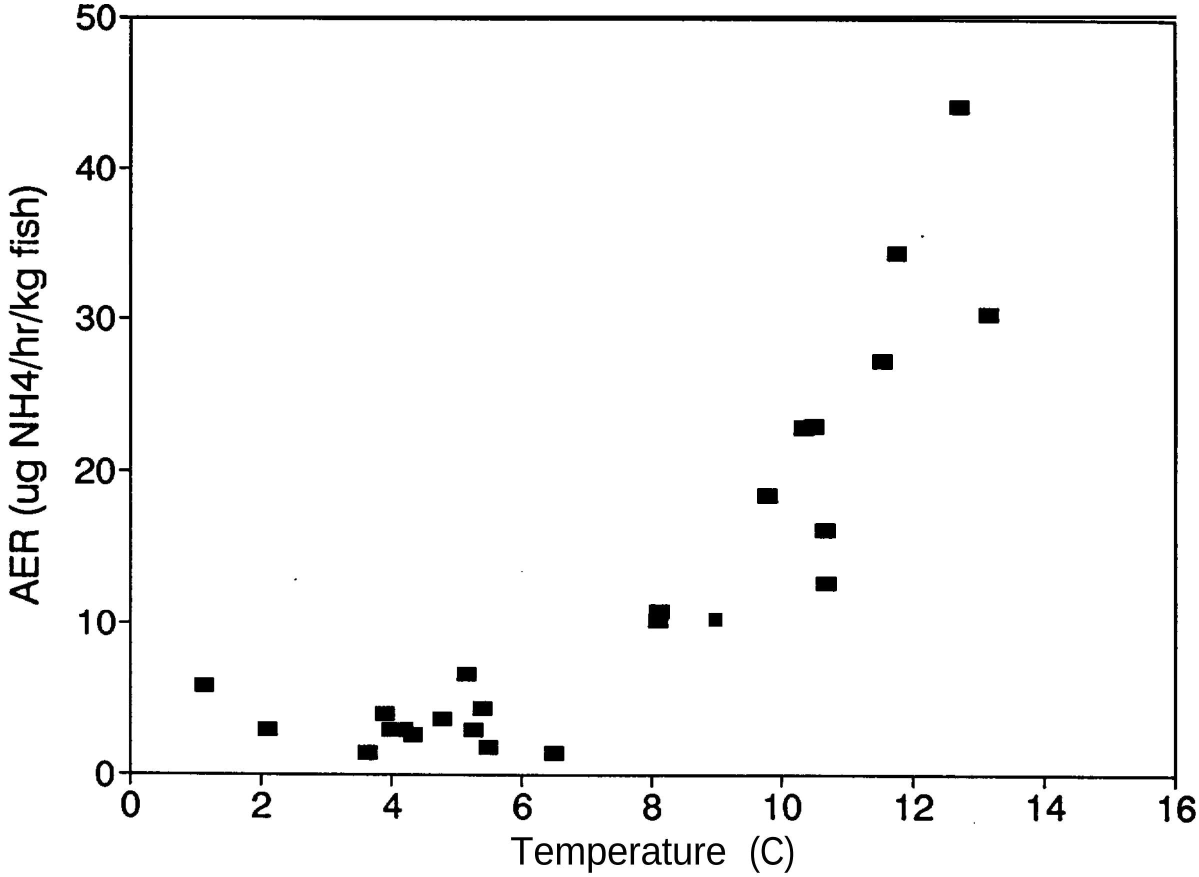
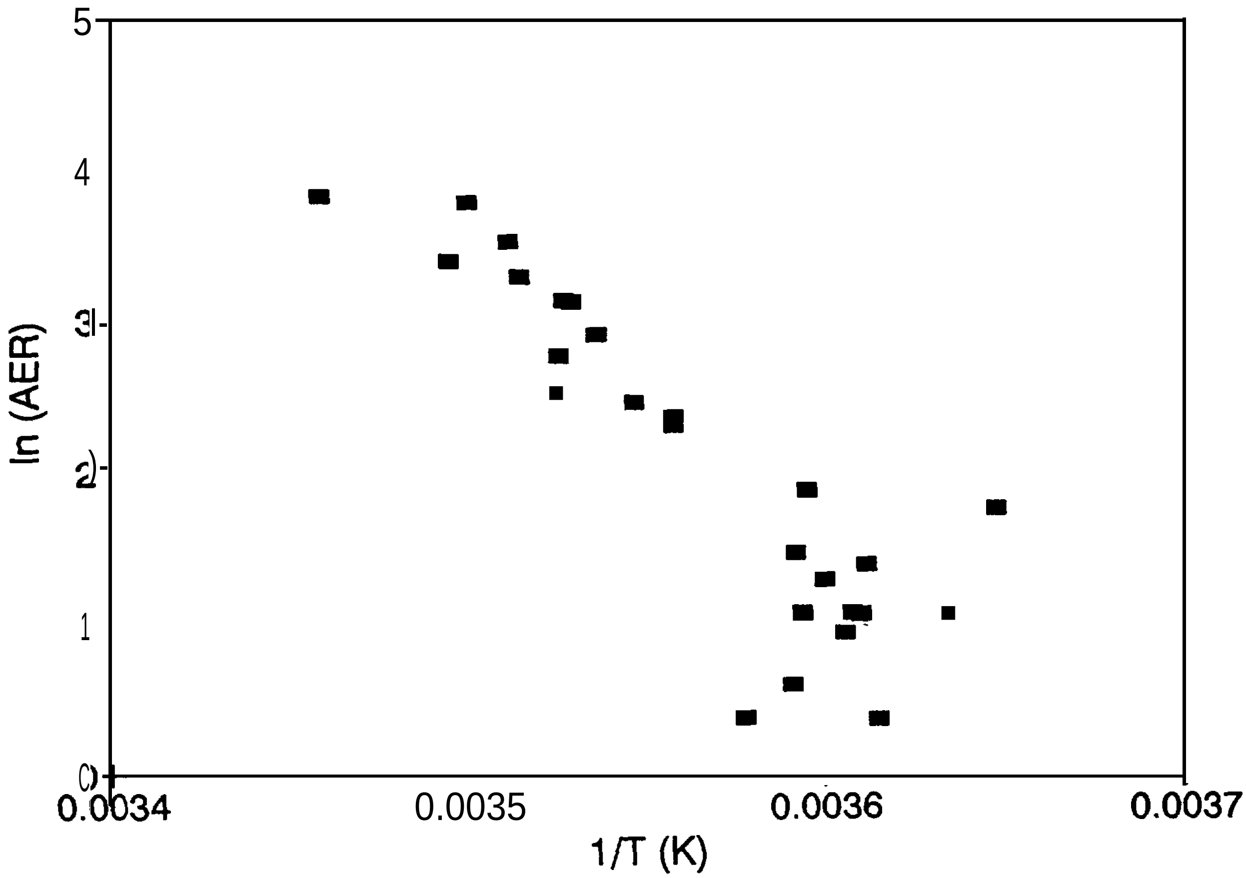


Figure 14. Ammonium excretion rate (AER) as a function of temperature in degrees Centigrade. The example shown is for group D2 during rearing year 1993-1994.



50
40
30
20
10
0
AER (ug NH4/hr/kg fish)
0
2
4
6
8
10
12
14
16
Temperature (C)

Figure 15. Relationship between In (ammonium excretion rate) and l/T (in degrees K). The example shown is for group D2 during rearing year 1993-1994.



ln (AER)
5
4
3
2
1
0
0.0034
0.0035
0.0036
0.0037
1/T (K)

and 1993-1994 (Table 6). However, there were differences in slopes in the rearing year 1991-1992. This can be discerned by an inspection of the regressions in Table 5. Graphic illustration of the similarity of these slopes during the four rearing years is shown in Fig 16.

The elevations of each line were also tested by analysis of covariance. In each rearing year, there were significant differences in elevations (Table 6). These results suggest that although the response of AER to temperature change is similar in the different groups of fish (similar slopes), the magnitude of the response may vary with the treatment of the fish.

The effects of water temperature on AER for individual experimental groups was also examined between rearing years. Results of analysis of covariance of Arrhenius plots for individual groups for rearing years 1991-1992, 1992-1993, and 1993-1994 (Table 7) indicated that no significant differences between slopes for different rearing years was found in any of the groups except group C. Conversely, significant differences in elevation were found between years for all groups except group G. Graphic illustration of some of these differences is shown in Fig. 17, using simulated Arrhenius plots derived from the equations in Table 5. When data from rearing year 1990-1991 were included, the differences between slopes were almost always significant, reflecting the unusual slopes derived from data from 1990-1991 (described above).

Average slopes for experimental groups during the three experimental brood years (excluding 1990-1991) (Table 8) were

Table 5. Regression analysis for Arrhenius plots of the reciprocal of temperature in degrees Kelvin and natural log of ammonium excretion rate. Values represent data from August to March of rearing years 1990-1991, 1991-1992, 1992-1993, and 1993-1994.

Year, group	Slope	Intercept	R^2	N
1990-1991				
Al	- 4819.0	18.95	0.124	28
Bl	- 5363.0	20.89	0.245	25
Cl	- 6656.2	25.35	0.221	30
Dl	- 5716.1	22.17	0.158	30
El	- 5594.0	23.24	0.245	28
Fl	-11807.0	44.73	0.579	29
Gl	-10327.1	39.34	0.447	29
1991-1992				
Al	-17484.4	64.36	0.797	25
Bl	-14699.9	54.48	0.501	25
Cl	-21743.3	79.40	0.796	25
Dl	-19055.8	69.61	0.742	25
El	-14766.1	54.73	0.687	25
Fl	-19806.7	73.14	0.821	25
Gl	-13768.6	51.67	0.505	25
A2	-17018.3	62.86	0.884	25
B2	-19047.3	70.16	0.885	25
c2	-21622.6	78.98	0.854	24
D2	-21320.4	77.92	0.865	25
E2	- 8840.7	33.88	0.452	25
F2	-21801.3	80.36	0.765	23
G2	-15353.6	56.89	0.497	24

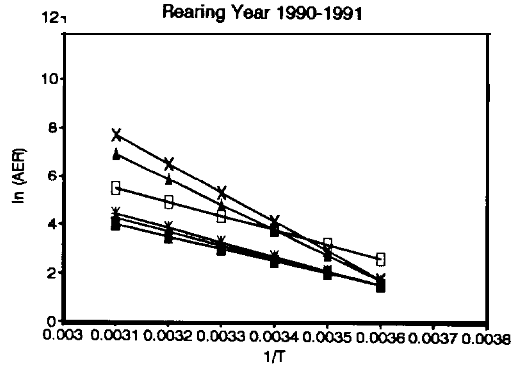
Table 5. (cont.)

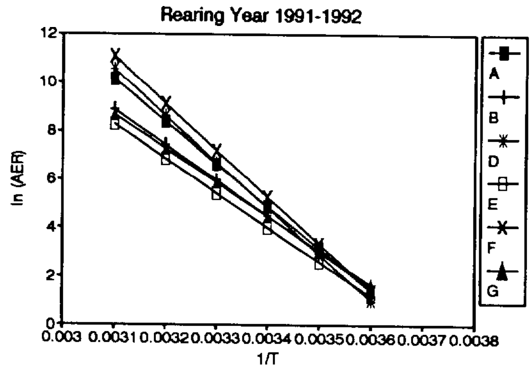
Year, group	Slope	Intercept	R^2	N
1992-1993				
Al	-16505.3	60.73	0.697	21
Bl	-14840.4	54.63	0.528	20
Cl	-13186.0	48.75	0.619	21
Dl	-15053.7	55.43	0.800	21
El	-11462.6	42.73	0.386	19
Fl	-15268.7	56.32	0.587	19
Gl	-14804.1	54.93	0.607	19
A2	-19097.9	70.11	0.850	19
B2	-17463.2	64.33	0.702	19
c2	-13003.1	47.97	0.708	18
D2	-18895.7	69.10	0.801	19
.E2	-13830.0	51.60	0.791	20
F2	-15294.3	56.70	0.834	20
G2	-13492.2	50.24	0.566	20
1993-1994				
Al	-18059.6	66.86	0.749	26
Bl	-18521.7	68.50	0.786	23
Cl	-15800.9	58.22	0.567	22
Dl	-18803.1	68.87	0.850	24
El	-14872.5	55.41	0.693	26
Fl	-18795.1	69.56	0.812	25
Gl	-17345.2	64.35	0.595	25
A2	-18628.1	68.62	0.741	26
B2	-12482.2	46.92	0.649	24
c2	-16396.0	60.52	0.697	25
D2	-19825.7	72.74	0.770	26
E2	-14141.4	52.87	0.665	25
F2	-14458.6	53.98	0.650	25
G2	-22201.9	81.46	0.697	24

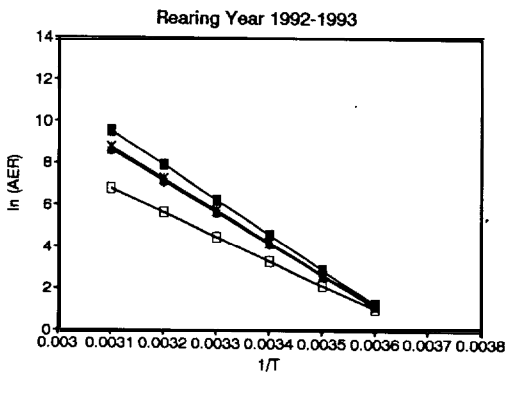
Table 6. Results from analysis of covariance for Arrhenius plots of the reciprocal of temperature in degrees Kelvin and natural log of ammonium excretion rate between experimental raceways for single rearing years. Values represent calculations from data from August to March of rearing years 1990-1991, 1991-1992, 1992-1993, and 1993-1994.

Year, test	Deg.Freed.	F	$F_{0.95}$	
1990-1991				
Slope	6, 185	1.477	2.15	N. S.
Elevation	7, 191	9.403	2.06	Sig.
1991-1992				
Slope	13, 318	35.000	1.75	Sig.
Elevation	14, 331	2.381	1.72	Sig.
1992-1993				
Slope	13, 241	0.609	1.77	N. S.
Elevation	14, 254	12.190	1.74	Sig.
1993-1994				
Slope	13, 318	1.249	1.75	N. S.
Elevation	14, 331	3.178	1.72	Sig.

Figure 16. Simulated Arrhenius plots calculated from the data shown in Table 5 for experimental raceways during the four rearing years at Willamette Hatchery.


Rearing Year 1990-1991
ln (AER)
1/T
0 2 4 6 8 10 12
0.003 0.0031 0.0032 0.0033 0.0034 0.0035 0.0036 0.0037 0.0038


Rearing Year 1991-1992
ln (AER)
1/T
0 2 4 6 8 10 12
0.003 0.0031 0.0032 0.0033 0.0034 0.0035 0.0036 0.0037 0.0038
A
B
D
E
F
G


Rearing Year 1992-1993
ln (AER)
1/T
0 2 4 6 8 10 12 14
0.003 0.0031 0.0032 0.0033 0.0034 0.0035 0.0036 0.0037 0.0038

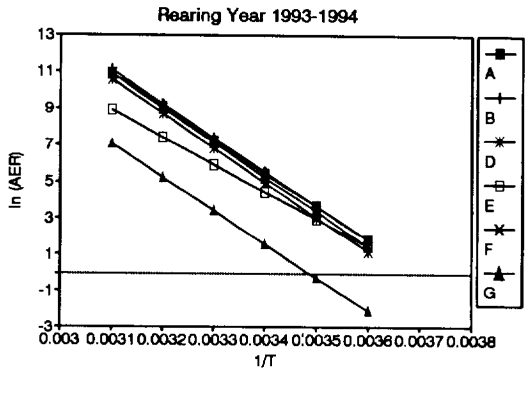
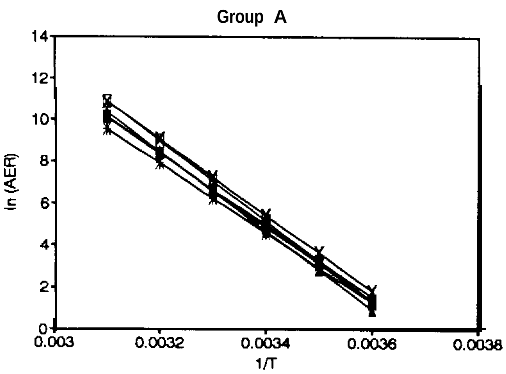
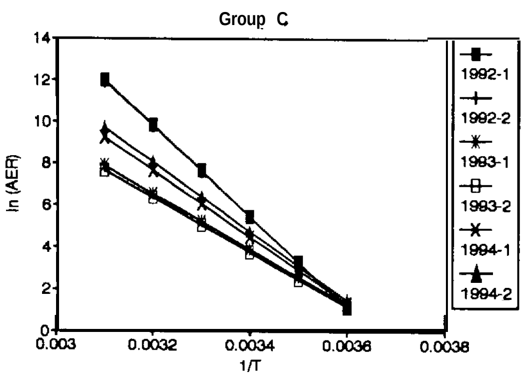

Rearing Year 1993-1994
ln (AER)
1/T
-3 -1 1 3 5 7 9 11 13
0.003 0.0031 0.0032 0.0033 0.0034 0.0035 0.0036 0.0037 0.0038
A
B
D
E
F
G

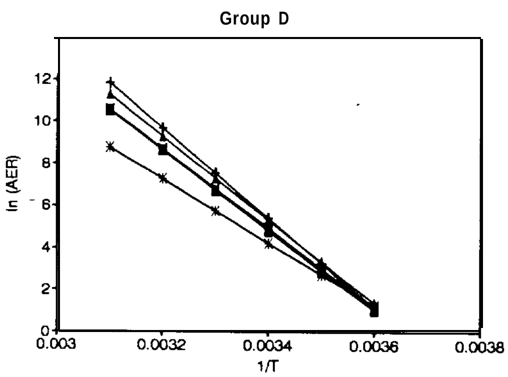
Table 7. Results from analysis of covariance for Arrhenius plots of the reciprocal of temperature in degrees Kelvin and natural log of ammonium excretion rate between rearing years for individual experimental groups. Values represent calculations from data from August to March of each rearing year.

Group, test	Deg.Freed.	F	$F_{0.95}$	
Group A				
Slope	5, 130	0.214	2.29	N.S.
Elevation	6, 135	4.389	2.06	Sig.
Group B				
Slope	5, 124	1.195	2.29	N.S.
Elevation	6, 129	5.209	2.16	Sig.
Group C				
Slope	5, 123	2.380	2.29	Sig.
Elevation	6, 128	2.665	2.17	Sig.
Group D				
Slope	5, 128	1.058	2.29	N.S.
Elevation	6, 133	2.333	2.17	Sig.
Group E				
Slope	5, 126	1.428	2.29	N.S.
Elevation	6, 131	2.786	2.17	Sig.
Group F				
Slope	5, 123	1.846	2.29	N.S.
Elevation	6, 128	7.023	2.17	Sig.
Group G				
Slope	5, 123	1.052	2.29	N.S.
Elevation	6, 128	1.992	2.17	N.S.

Figure 17. Simulated Arrhenius plots calculated from the data shown in Table 5 to show changes in slopes for individual experimental raceways between rearing years.


Group A
14
12
10
8
6
4
2
0
ln (AER)
0.003
0.0032
0.0034
0.0036
0.0038
1/T


Group C
14
12
10
8
6
4
2
0
ln (AER)
0.003
0.0032
0.0034
0.0036
0.0038
1/T
1992-1
1992-2
1993-1
1993-2
1994-1
1994-2


Group D
12
10
8
6
4
2
0
ln (AER)
0.003
0.0032
0.0034
0.0036
0.0038
1/T

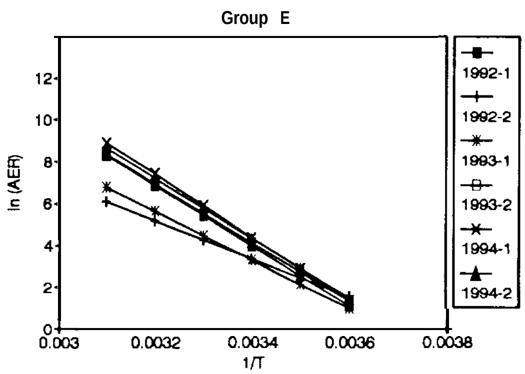

Group E
12
10
8
6
4
2
0
ln (AER)
0.003
0.0032
0.0034
0.0036
0.0038
1/T
1992-1
1992-2
1993-1
1993-2
1994-1
1994-2

Table 8. Results from analysis of covariance for Arrhenius plots of the reciprocal of temperature in degrees Kelvin and natural log of ammonium excretion rate between rearing years for individual experimental groups. Values represent calculations from data from August to March of each rearing year.

Group	Mean Slope from ANCOVA	Mean Slope from Table 5	Mean Intercept from Table 5
A	-17,202.6	-17,799.0	65.59
B	-15,438.2	-16,175.a	59.84
C	--[a]	-16,958.7	62.31
D	-18,465.3	-18,825.7	68.95
E	-13,817.3	-12,895.8	47.81
F	-18,261.8	-17,483.7	64.33
G	-17,433.3	-16,377.6	59.69

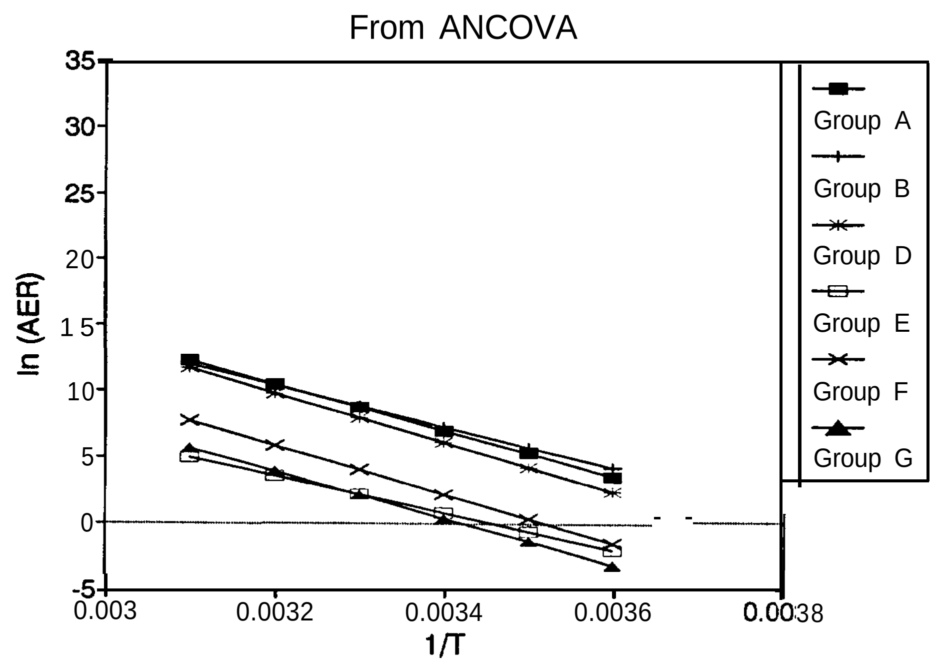
[a]An average slope cannot be calculated because slopes were significantly different (Table 7).

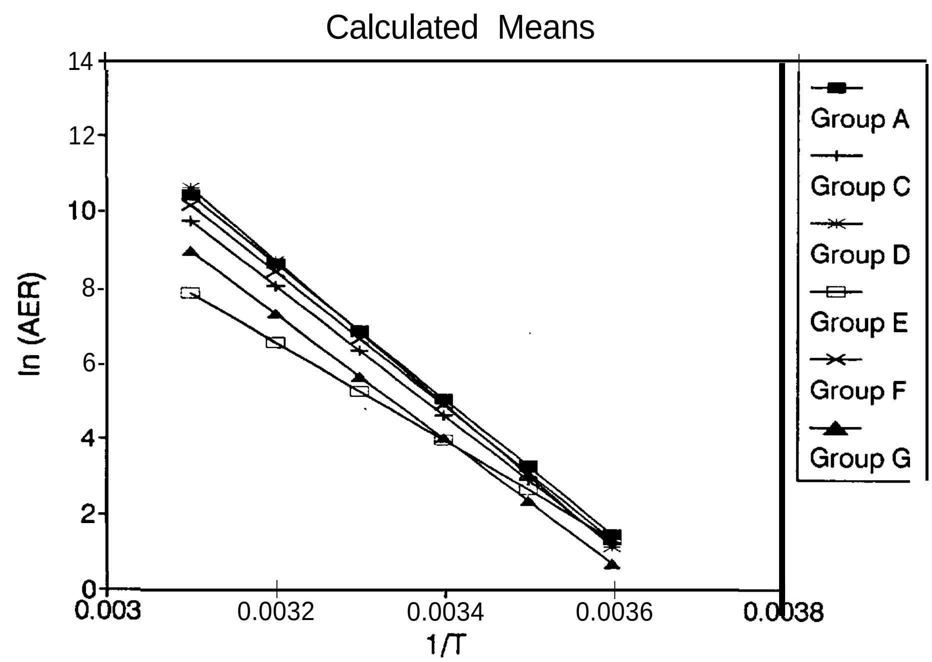
calculated by analysis of covariance and by simple means. Graphic illustration of these averages is presented in Fig. 18. Averages by simple means (Fig. 18B) showed little differentiation between raceways and Michigan ponds, whereas average slopes by analysis of covariance showed a clear distinction between relationships in raceways and in Michigan ponds (Fig. 18A). Of these two, the average slopes from analysis of covariance should be considered the most accurate because they are derived from actual data rather than means of slopes from regression equations. These results suggest that there was a differential responsiveness of AER to temperature between the raceways and the Michigan ponds.

Effect of Fish Size on AER

The relatively high values for R^2 for the relationships between AER and water temperature shown in Table 5 indicate that 60-80% of the variation in AER during the year could be explained from changes in water temperature. Unfortunately, in a hatchery situation, many other variable are correlated to but not necessarily caused by water temperature. For example, fish also increased in size with time of rearing. While growth of the fish was related to water temperature, a decrease in AER with increased size could also account for some of the apparent drop in AER with season.

Figure 18. Simulated Arrhenius plots using mean slopes for the relationship between In (AER) and l/T for different experimental groups during the four rearing years at Willamette Hatchery. A. Mean slopes derived from analysis of covariance. B. Mean slopes derived from simple averages of the slopes shown in Table 5.


From ANCOVA
ln (AER)
35
30
25
20
1 5
10
5
0
-5
0.003
0.0032
0.0034
0.0036
0.0038
1/T
Group A
Group B
Group D
Group E
Group F
Group G


Calculated Means
ln (AER)
14
12
10
8
6
4
2
0
0.003
0.0032
0.0034
0.0036
0.0038
1/T
Group A
Group C
Group D
Group E
Group F
Group G

It was not possible to examine the changes in AER in relation to growth in the present hatchery experiments. Regressions would show a negative relationship, but this most likely was caused by changes in water temperature, which tended to cool as the season progressed. The effects of size, and growth on AER were instead addressed by laboratory experiments where the AERs of different sizes of fish could be measured at similar times and temperatures. Unfortunately, laboratory juvenile chinook salmon were unavailable for use when this question arose. However, an experiment with juvenile coho salmon reared in the laboratory permitted a partial answer to this question. Results from these experiments are described at the end of this report.

Estimation of Population Size by Ammonium Excretion Rate

If it is assumed that size has little effect on ammonium excretion rate, or if the size at the fish at the time of measurement is held relatively constant, it is possible to use the equations derived from the Arrhenius plots to determine population size in the raceways. Nearly 80% of the variation in AER during the year can be ascribed to changes in temperature so the calculations become more simplified.

For these calculations, the average slopes and intercepts derived from ANCOVA calculations for groups A, B, and D for three rearing years were used. It can be seen in Fig. 18 that the average slopes for these three ponds were very similar for rearing years 1991-1992, 1992-1993, and 1993-1994. The average slope for these three groups was -17,035, while the average intercept was 64.8. The equation for calculation of AER therefore becomes:

$$\ln(AER) = (-17{,}035*1/T) + 64.8 \quad (7)$$

or

$$AER = \exp((-17{,}035*1/T) + 64.8) \quad (8)$$

where AER is the ammonium excretion rate in mg NH_4/hr/kg fish. By rearrangement:

$$\text{kg fish} = (\text{mg } NH_4/\text{hr})/(\exp((-17{,}035*1/T) + 64.8) \quad (9)$$

But

$$\text{population number } (N) = \text{kg fish} * (\text{fish/kg}) \quad (10)$$

Therefore,

$$N = ((\text{mg } NH_4/\text{hr})/(\exp((-17{,}035*1/T) + 64.8)))*(\text{fish/kg}) \quad (II)$$

The first term, mg NH_4/hr can be determined by the concentration of NH_4 at the effluent in mg/L and the current flow in L/hr. The remaining variables are water temperature in degrees Kelvin and fish/kg determined from pond counts.

Examples of estimated populations at release using these calculations are presented in Table.9. The population numbers derived from ammonium excretion vary widely around the number derived from inventories. In general, group B tended to be overestimated, while group D tended to be underestimated. This suggests a density factor may be important in these measurements. While the variation for estimates in Table 9 are too great to be of practical use, a number of factors could reduce the error

Table 9. Calculations of population numbers using ammonium excretion rates. Population numbers were calculated near the time of release for comparison to population numbers derived from pond inventories and water displacements in liberation trucks.

Year, pond	Fish/kg	Pop. from Inventory	Pop. from Lib. Truck	Calculated Population	Percent of Invent. Population
1 9 9 2					
Al	22.90	39,330	38,881	47,650	121.2
A2	23.28	39,728	38,511	34,985	88.1
Bl	19.89	20,538	19,345	22,993	112.0
B2	22.57	20,037	21,546	20,873	104.2
Dl	27.04	118,763	113,436	118,780	100.0
D2	29.28	118,656	120,854	77,849	65.7
				Average	98.5 $\pm$ 8.0
1993					
Al	20.4	39,235	37,014	23,957	61.1
A2	20.9	39,224	36,480	45,582	116.2
Bl	19.9	19,788	17,792	23,370	118.1
B2	21.1	19,663	19,968	31,859	162.0
Dl	20.7	118,121	101,943	55,564	47.0
D2	21.2	119,008	105,792	60,463	50.8
				Average	92.5 $\pm$ 19.0
1994					
Al	34.9	39,364	38,955	69,876	177.5
A2	33.1	39,273	36,525	45,765	116.5
Bl	29.7	19,950	17,550	41,625	208.6
B2	28.6	19,759	17,550	21,969	111.2
Dl	37.4	116,264	116,110	44,929	38.6
D2	35.7	116,180	108,378	65,814	56.6
				Average	18.2 $\pm$ 27.0

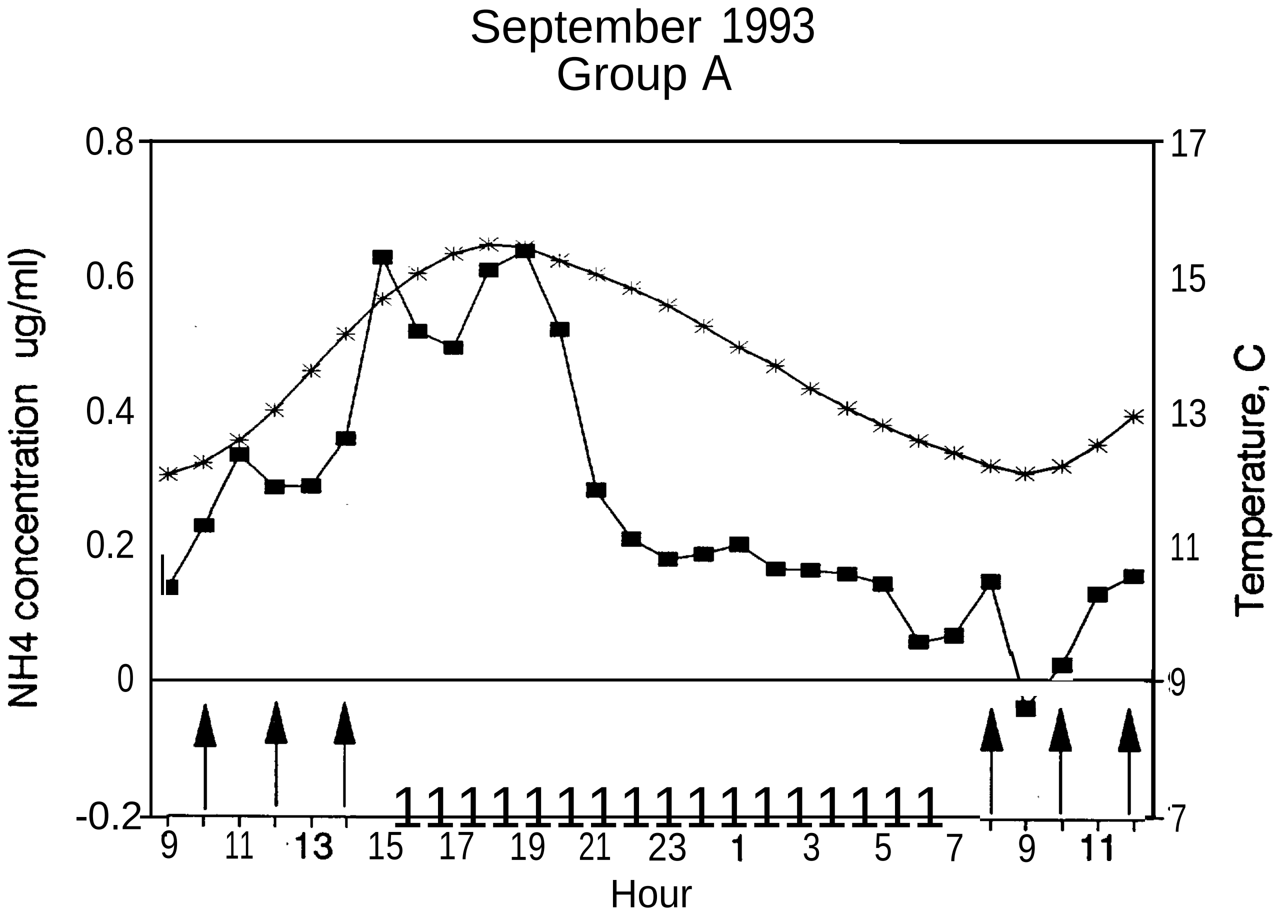
considerably: 1) Only single samples for ammonium analyses were taken during routine monitoring. These tend to vary considerable between replicates, especially if the ponds are dirty. A minimum of 5 replicates should be run if these numbers are to be used for population estimates. 2) Temperature data in 1993 were not available, so rough estimates of temperature were used. 3) It was not known whether the fish were fasted during the period in 1992 rearing when the ammonium samples were taken. The extent of feeding will influence the ammonium excretion considerably.

If it were possible to make estimates of fish populations through metabolic parameters, this would alleviate some of the handling stress involved in determining population numbers, especially in populations that need not be transported in liberation trucks. However, this method would require knowledge of water temperatures, flows, and fish size. At the moment, the method looks promising enough to suggest further refinement.

Die1 Changes in Ammonium Excretion Rate

Ammonium ion excretion in chinook salmon followed a die1 pattern similar to that shown in the example for group A2 for September 7-8, 1993 (Fig. 19). Maximum excretion occurred from 1600 to 1900 hours in late afternoon and evening when water temperatures were highest. Minimum excretion occurred from 600 to 1000 hours in the morning when water temperatures were lowest. The spiked appearance of the curve suggested increased ammonium

Figure 19. Die1 changes in ammonium concentrations at the effluent end of the raceway containing chinook salmon from group A2. Measurements were taken in September 1993. Temperature is represented by asterisks. Arrows show approximate times of feeding.

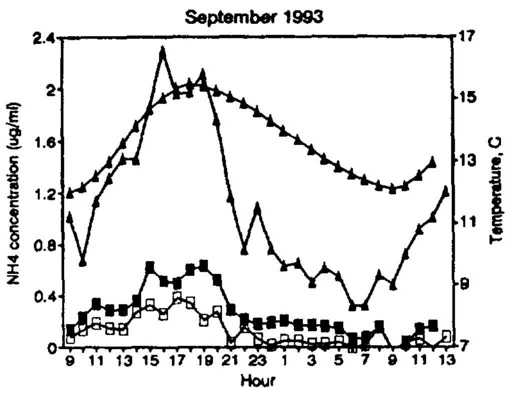

September 1993
Group A
NH4 concentration ug/ml)
Temperature, C
Hour
0.8
0.6
0.4
0.2
0
-0.2
17
15
13
11
9
7
9
11
13
15
17
19
21
23
1
3
5
7
9
11

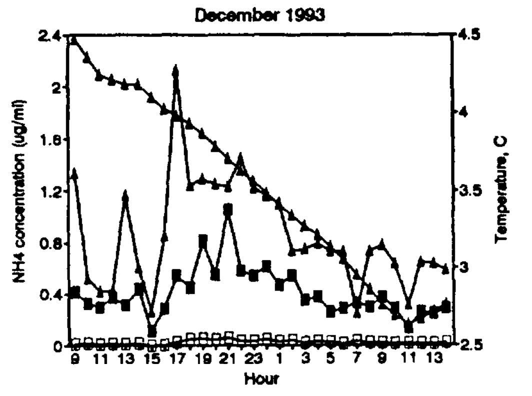
excretion near time of feeding, although there was not a well-defined correspondence. The present experiments were not designed to determine the effects of feeding on AER. Determination of these effects have been accomplished in laboratory studies (Rychly 1980; Beamish and Thomas 1984; Ming 1985; Kaushik and Gomes 1988; Kaushik and Cowey 1991)

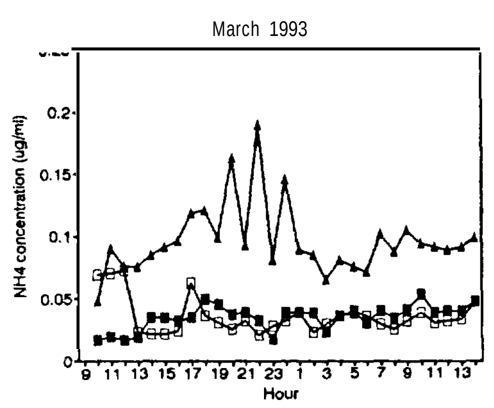
Die1 changes in effluent ammonium concentrations were observed in raceways (Fig. 20) and Michigan ponds (Fig. 21) in September, December, March, and February. In February 1994, the fish had been starved for three days prior to sampling. The effluent concentrations of ammonium ions were found to be much lower and consequently results were not comparable to the other three time periods. Urea excretion, however, was increased in these fish (see later section). In each instance, the maximum ammonium concentration in the effluent was reached at about 1600 hours regardless of the changes in water temperature.

Die1 changes in AERs were calculated for raceways (Fig. 22) and Michigan ponds (Fig. 23) for September, December, March and February. In raceways, all groups seem to follow similar die1 cycles in September and December. No real cycle was apparent in February or March. In September, group D seemed to have the highest excretion rate. None of the groups was consistently lower than the others. In December and March, group B seemed to have the highest rate while group C seemed to have the lowest. In Michigan ponds, there was considerable variation in values and cyclic changes were not as apparent as in the ammonium concentrations of the effluent water. In September, group E

Figure 20. Die1 changes in ammonium concentration (ug/ml) at the effluent from ponds containing groups A2 (-■-), B2 (-□-), and D2 (-▲-) in September 1993, December 1993, March 1993, and February 1994. Water temperatures (-✱-) are also shown for September 1993, December 1993, and February 1994.


September 1993
NH4 concentration (ug/ml)
Temperature, C
Hour


December 1993
NH4 concentration (ug/ml)
Temperature, C
Hour


March 1993
NH4 concentration (ug/ml)
Hour

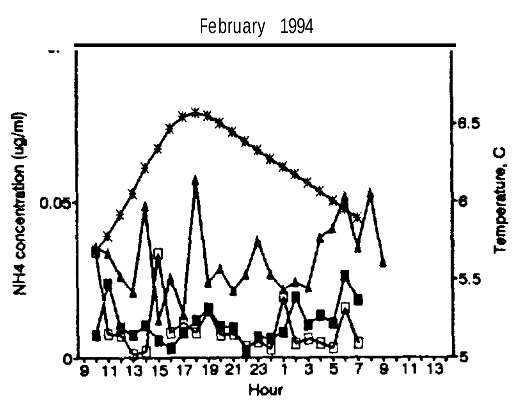
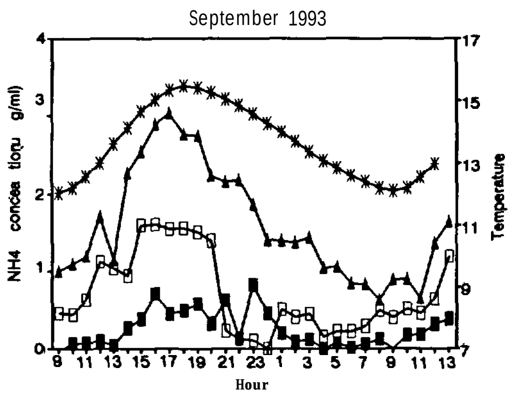
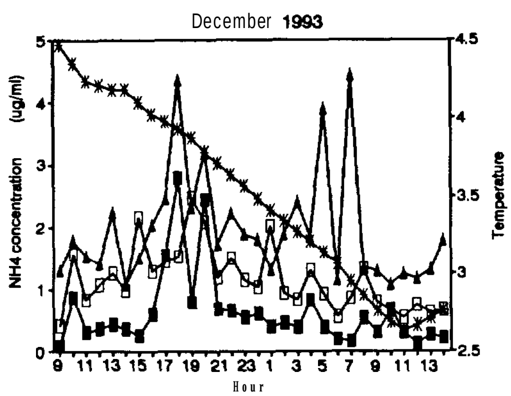
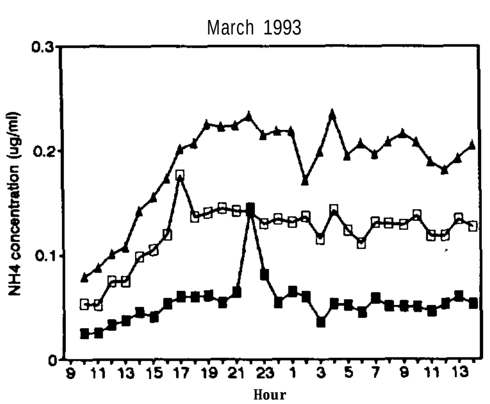

February 1994
NH4 concentration (ug/ml)
Temperature, C
Hour

Figure 21. Die1 changes in ammonium concentration (ug/ml) at the effluent from ponds containing groups El (-■-), F1 (-□-), and G1 (-▲-) in September 1993, December 1993, March 1993, and February 1994. Water temperatures (-✱-) are also shown for September 1993, December 1993, and February 1994.


September 1993
NH4 concentration (ug/ml)
Temperature
Hour
0
1
2
3
4
7
9
11
13
15
17
9 11 13 15 17 19 21 23 1 3 5 7 9 11 13


December 1993
NH4 concentration (ug/ml)
Temperature
Hour
0
1
2
3
4
5
2.5
3
3.5
4
4.5
9 11 13 15 17 19 21 23 1 3 5 7 9 11 13


March 1993
NH4 concentration (ug/ml)
Hour
0
0.1
0.2
0.3
9 11 13 15 17 19 21 23 1 3 5 7 9 11 13

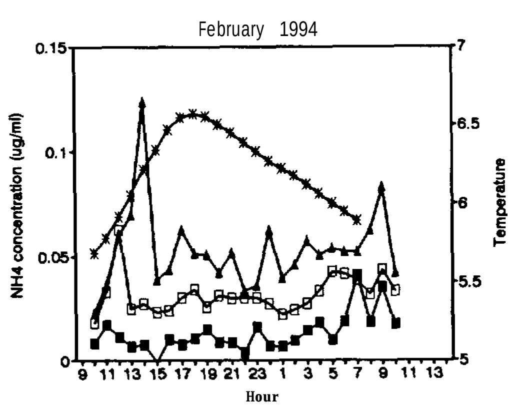
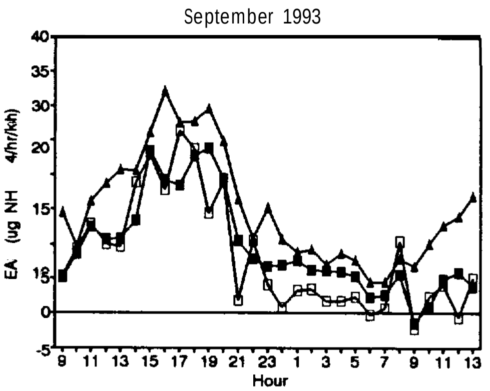
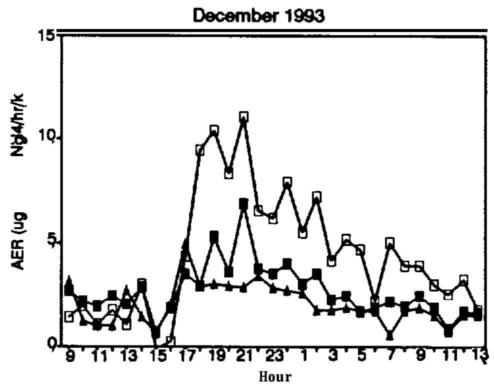
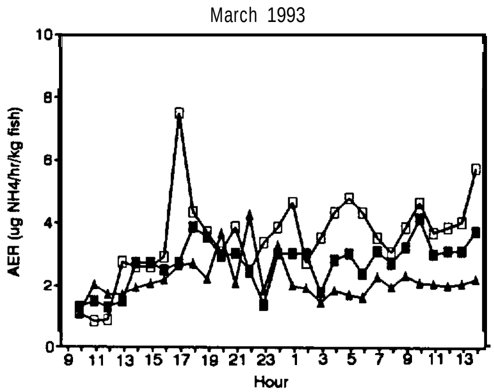

February 1994
NH4 concentration (ug/ml)
Temperature
Hour
0
0.05
0.1
0.15
5
5.5
6
6.5
7
9 11 13 15 17 19 21 23 1 3 5 7 9 11 13

Figure 22. Diel changes in ammonium excretion rates (ug NH_4/hr/kg fish) in ponds containing groups A2 (-■-), B2 (-a-), and D2 (-▲-) in September 1993, December 1993, March 1993, and February 1994.


September 1993
EA (ug NH 4/hr/kh)
Hour


December 1993
AER (ug NH4/hr/k
Hour


March 1993
AER (ug NH4/hr/kg fish)
Hour

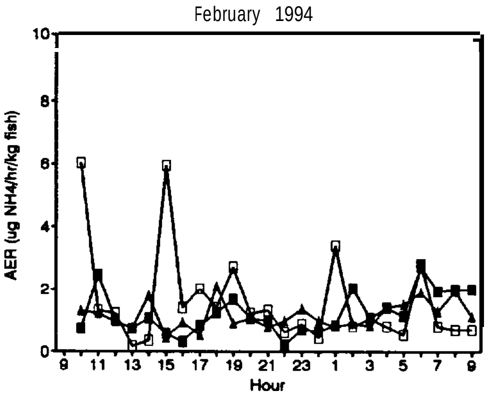
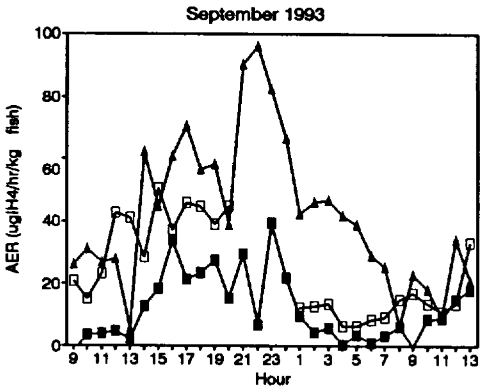
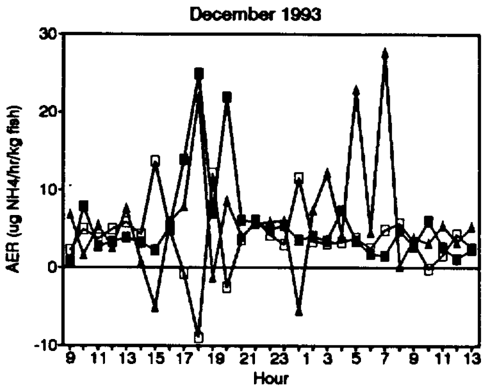
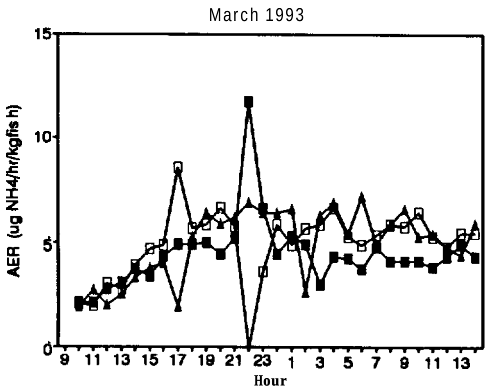
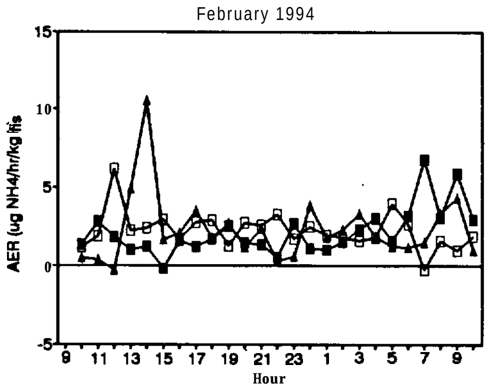

February 1994
AER (ug NH4/hr/kg fish)
Hour

Figure 23. Die1 changes in ammonium excretion rates (ug NH4/hr/kg fish) in ponds containing groups E1 (-■-), F1 (-□-), and G1 (-▲-) in September 1993, December 1993, March 1993, and February 1994.


September 1993
AER (ug/H4/hr/kg fish)
Hour
0
20
40
60
80
100
9 11 13 15 17 19 21 23 1 3 5 7 9 11 13


December 1993
AER (ug NH4/hr/kg fish)
Hour
-10
0
10
20
30
9 11 13 15 17 19 21 23 1 3 5 7 9 11 13


March 1993
AER (ug NH4/hr/kgfis h)
Hour
0
5
10
15
9 11 13 15 17 19 21 23 1 3 5 7 9 11 13


February 1994
AER (ug NH4/hr/kg fis
Hour
-5
0
5
10
15
9 11 13 15 17 19 21 23 1 3 5 7 9

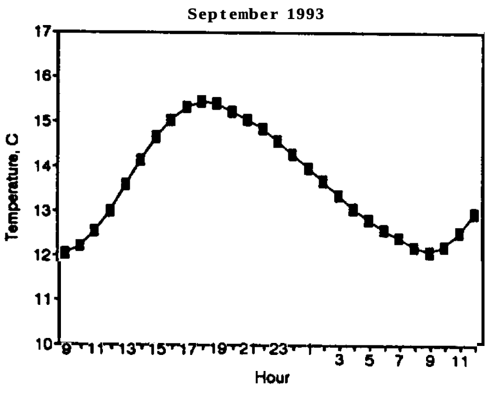
seemed to have the lowest rate while group G had the highest rate. By December, this difference was lost, although in March, there was again a tendency for the rate in group E to be the lowest.

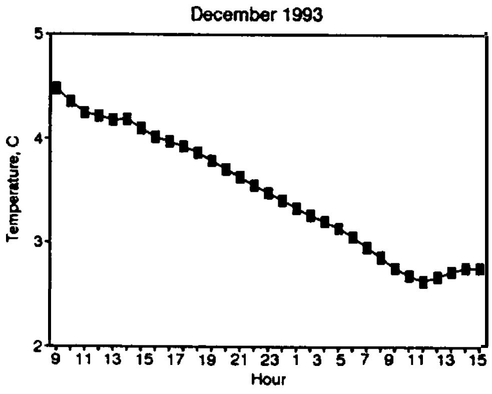
A rigorous test for statistical differences between the curves required transformations of the data to generate straight lines. This could not be done using die1 hours because the curves did not follow the sinusoidal curve expected from a purely diei rhythms.

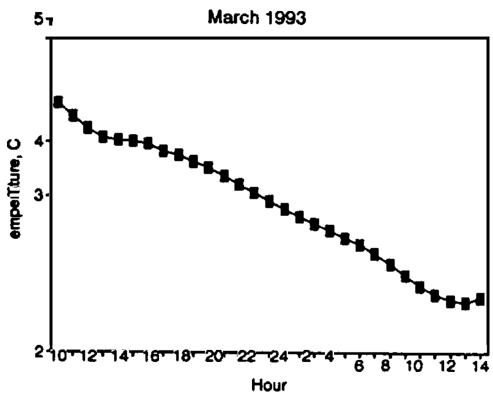
The influence of temperature was examined in relation to the die1 cycles in AER using data from the continuous monitoring system. Temperatures fluctuated greatest in September (Fig 24) with a maximum water temperature of 16 C and a minimum of 12 C. Similarly, temperatures during the February sampling reach a maximum of about 6.6^{O}C at 1800 hours and a minimum of about 5.8^{O}C at 1000 hours. The shape of these curves was nearly sinusoidal, but other water temperature curves from December and March showed decreasing trends.

Ammonium excretion rates were transformed to Arrhenius plots, where the reciprocal of temperature in degrees Kelvin was plotted against the natural log of AER. Regression equations and coefficients are presented in Table 10. Regression coefficients in most cases in September and March were low but the regressions were significantly different from zero. Most of the regression coefficients from samples from December and February showed that the relationships were not significantly different from zero. The reason for the low regression coefficients could be

Figure 24. Water temperatures during die1 measurements of ammonium concentrations in experimental ponds at Willamette Hatchery. A. September 1993. B. December 1993. C. March 1993. D. February 1994.


September 1993
Temperature, C
Hour


December 1993
Temperature, C
Hour


March 1993
empeiTture, C
Hour

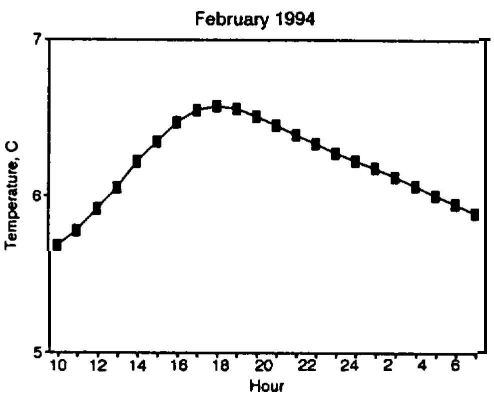
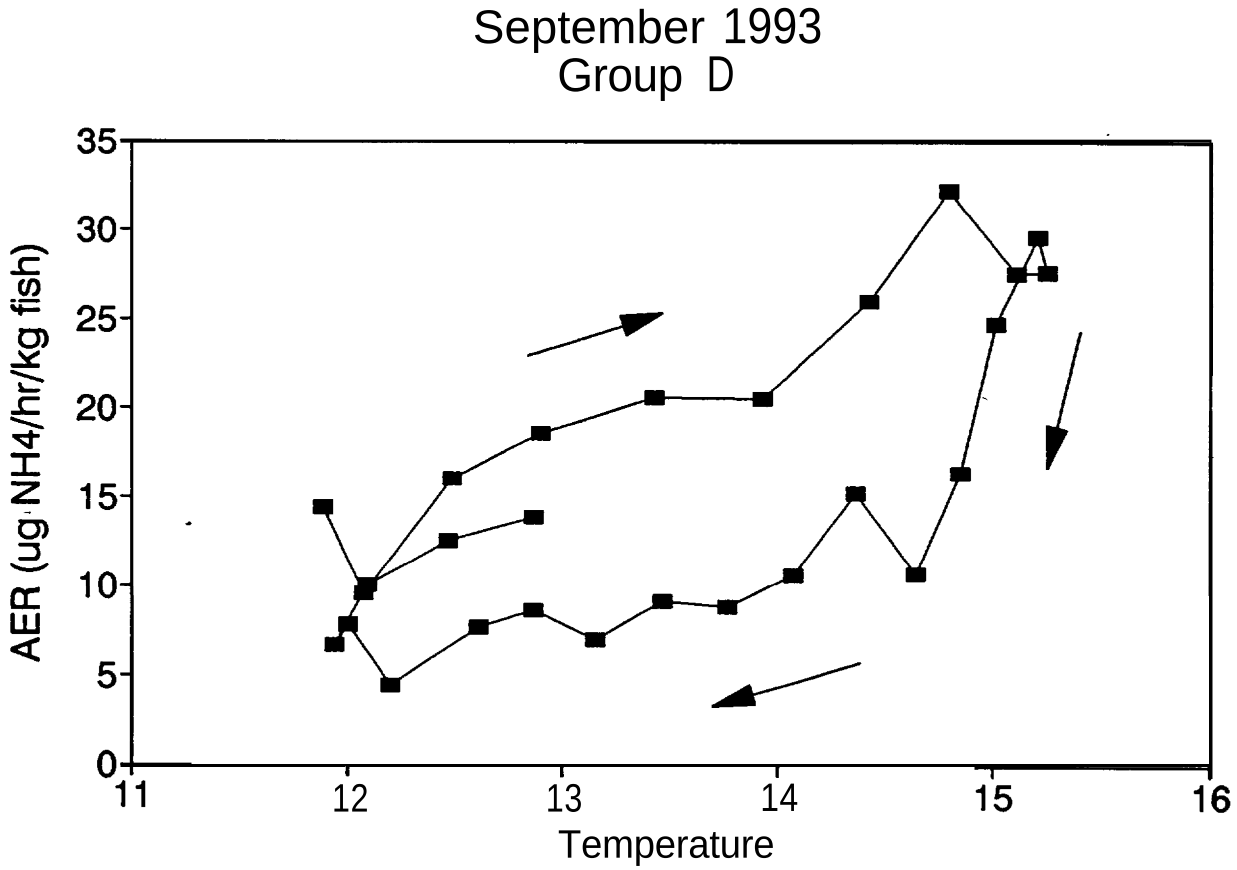

February 1994
Temperature, C
Hour

Table 10. Regression analysis for Arrhenius plots of the reciprocal of temperature in degrees Kelvin and natural log of ammonium excretion rate. Values represent data from die1 changes in AER and temperature for 24-30 hour periods in September 1993, December 1993, March 1993, and February 1994. Values marked with an asterisk are significant at the 95% level.

Month, group	Slope	Intercept	R2	N
September 1993				
A2	-38699.3	137.05	0.546*	27
B2	-32058.2	113.53	0.196*	25
c2	-52287.6	184.45	0.635*	26
D2	-26489.3	95.07	0.491*	27
El	-50977.5	179.95	0.402*	25
Fl	-29452.6	105.72	0.450*	23
Gl	-34060.3	122.29	0.464*	27
December 1993				
A2	-17219.8	63.17	0.077	29
B2	26055.3	-92.96	0.054	28
c2	-35536.6	128.71	0.123	28
D2	-15186.5	55.54	0.048	29
El	-26696.0	97.98	0.068	29
Fl	-22992.8	84.54	0.129	25
Gl	- 1457.0	6.89	0.0001	26
March 1993				
A2	-29134.1	105.83	0.357*	29
B2	-51027.7	184.85	0.496*	29
c2	-14669.3	53.59	0.047	29
D2	-23227.4	84.35	0.352*	29
El	-36760.5	133.75	0.588*	29
Fl	-37107.9	135.16	0.546*	28
Gl	-36509.6	132.90	0.348*	29
February 1994				
A2	69389.7	-248.55	0.143	22
B2	- 8196.0	29.52	0.001	22
c2	47190.5	-168.62	0.094	22
D2	41033.6	-146.92	0.131	24
El	77274.5	-276.16	0.236*	24
Fl	-25592.0	92.45	0.051	24
Gl	-41257.2	148.37	0.030	24

Figure 25. Relationship of AER to water temperature for fish in group D2 measured in September 1993. Arrows show the progression of AERs and temperature during a 30-hour period. Increasing AERs and temperatures occurred during the daytime when the fish were active, while decreasing AERs and temperatures occurred at night when the fish were quiescent.

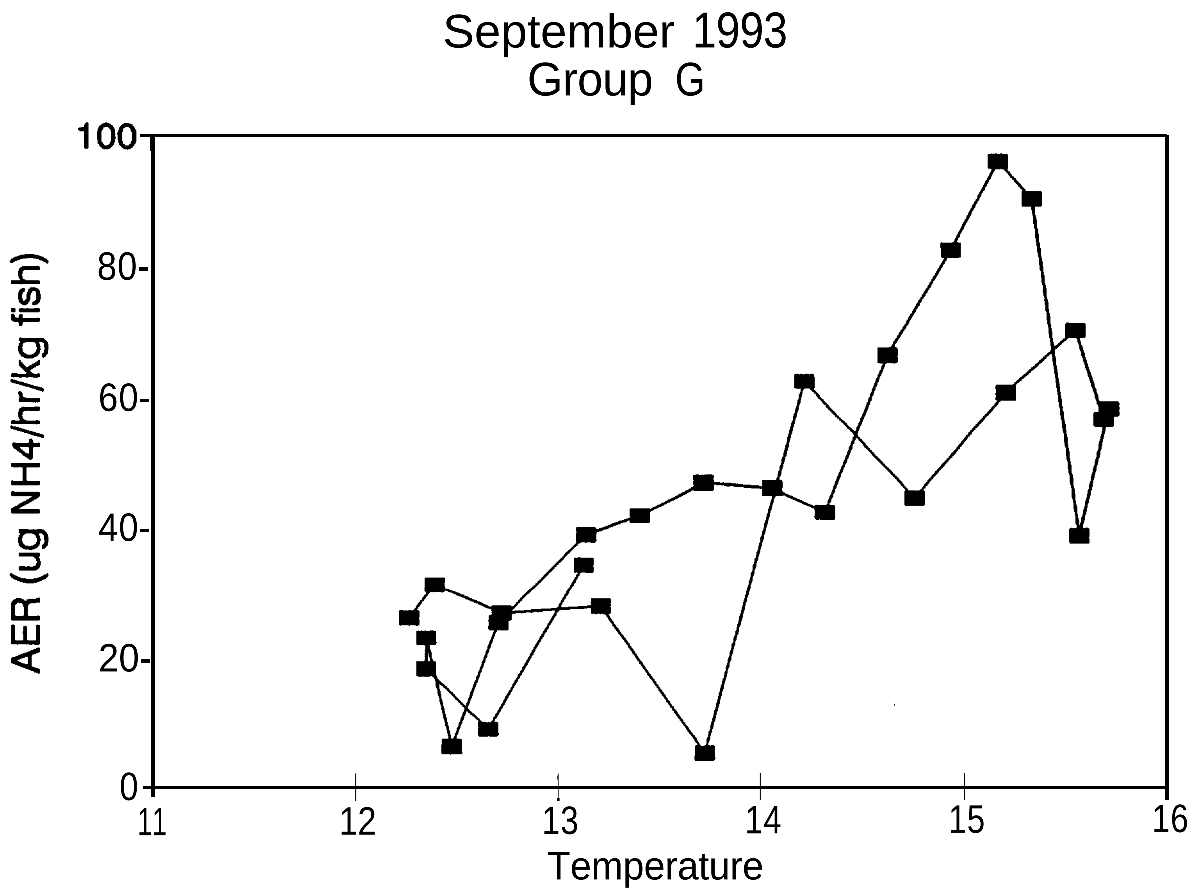

September 1993
Group D
AER (ug NH4/hr/kg fish)
35
30
25
20
15
10
5
0
11
12
13
14
15
16
Temperature

illustrated with AERs from group D2 measured in September. When plotted against water temperature (Fig. 25), a cycle of changes in AER was found, where AERs leading up to the maximum temperature were greater than those leading down from the maximum temperature. This could be explained by the activity of the fish and the temperature of the water. Maximum water temperature in September occurred at about 1800 hours (Fig. 24), at the end of feeding in the evening. During the day, when the fish were active with feeding, the AER was greater at a particular temperature than in the evening and night when the fish were quiescent. When the AERs were divided into active phases and quiescent phases and transformed to Arrhenius plots (Table ll), the correlation coefficients were much higher for the active phase, suggesting a strong relationship between AER and water temperature during active feeding. Correlation coefficients were lower but significant for the quiescent phase (Table 11), probably because the AERs in the evening and night seemed to be biphasic. There was a rapid.decrease in AER from 1800 to 2200 hours, then a relatively flat AER from 2200 hours to 0700 hours the next day (Fig. 25). All groups except Gl followed this pattern. In group Gl, the AER was much greater and the quiescent phase was similar to the active phase (Fig. 26). This suggests that fish in this group were'more metabolically active, even during the quiescent phase. Bacterial degradation of waste may also have contributed a portion of ammonium to the effluent, although the ponds were kept relatively clean by the flushing action provided by the baffles (Boerson and Westers 1988).

Table 11. Regression analysis for Arrhenius plots of the reciprocal of temperature in degrees Kelvin and natural log of ammonium excretion rate during active hours (0700 to 1900 hours) and quiescent hours (1900 to 0700 hours). Values represent data from die1 changes in AER and temperature for 24-30 hour periods in September 1993. Values marked with asterisks are significant at the 95% level.

Group	Slope	Intercept	R^2	N
Active Period				
A2	-26356.6	97.46	0.810*	11
B2	-23801.9	85.54	0.720*	11
c2	-51549.0	182.15	0.925*	10
D2	-21560.8	78.23	0.849*	11
El	-58978.6	207.82	0.805"	10
Fl	-18061.8	66.39	0.599*	11
Gl	-27878.9	83.24	0.288*	12
Quiescent Period				
A2	-42727.3	150.89	0.644*	16
B2	-30296.4	106.85	0.178	15
c2	-46507.3	164.11	0.520*	17
D2	-26334.0	94.33	0.573*	17
El	-46124.4	163.03	0.272*	16
Fl	-28069.0	101.32	0.450*	13
Gl	-44205.6	157.72	0.633	16

Figure 26. Relationship of AER to water temperature for fish in group Gl measured in September 1993.


September 1993
Group G
AER (ug NH4/hr/kg fish)
100
80
60
40
20
0
11
12
13
14
15
16
Temperature

Regressions for Arrhenius plots in December, February, and March were mostly not significant from zero (Table 10). In many cases this resulted from little change in temperature but a cyclic change in ammonium excretion during feeding. AERs for these times were much lower than those observed for fish in September when the water was warmer.

Effects of Rearing Density on AER

Ammonium concentration of the effluent from experimental raceways increased with increased rearing density of the ponds (Ewing and Sheahan, 1992, Ewing et al. 1993, 1994). While this result was important for the well-being of the fish in the various groups, it did not address the question of whether rearing density affected the ammonium excretion rate per kg fish (AER). To examine the effect of density on AER, an arbitrary date at about the 15th of each month was selected. AERs were calculated for those particular dates (Table 12). Differences between the groups were tested by analysis of variance but the results indicated no significant difference between groups (Table 13), even though both rearing densities and individual AERs varied considerably (Table 12). Since analysis of variance compares the internal variation with the variation between groups, the large variation within a group probably rendered the test insensitive to changes between groups.

A better test of the differences in AER between groups was provided from the study of the die1 cycles of ammonium excretion.

Table 11 (cont.).

Rearing year, date	Ammoniun Excretion Rates (ug NW/hr/kg fish)													
	Al	A2	Bl	B2	Cl	c2	Dl	D2	El	E2	Fl	F2	Gl	G2
11/17	5.03		6.9.5		4.46		7.87		8.31		1.66		12.60	
11/19		3.49		8.00		2.18		2.79		4.30		5.79		2.46
12/08	2.77		6.74		4.22		2.87		5.36		3.25		15.61	
12/10		4.66		4.50		2.08		3.46		6.05		4.84		7.19
01/19	1.29		3.82		1.28		1.82		2.36		5.42		0.77	
01/21		3.20		2.67		3.18		5.19		4.37		1.54		6.84
02/16	6.16		2.46		4.20		2.41		6.42		5.25		9.11	
02/18		1.71		2.49		1.81		1.14		4.40		3.73		2.94
1993-1994														
08/17	58.14		48.24		32.34		24.04			42.85		58.63		66.62
08/19		32.47		16.54		28.17		34.36	35.80		37.75		72.91	
09/14	30.51		35.39		14.67		17.93			26.27		13.77		21.49
09/16		23.24		21.08		21.25		12.50	28.31		31.80		23.36	
10/14		18.76		21.83		10.13		18.35	14.46		35.19		27.48	
10/19	12.14		7.00		7.14		6.52			14.19		8.12		18.83
11/16	10.68		12.31		6.22		5.75			7.94		8.70		1.29
11/18		5.06		8.25		6.42		1.83	5.34		9.89		2.55	
12/14	6.79		7.76		3.99		3.97			0.00		11.75		6.20
12/16		5.11		11.84		1.05		2.93	5.64		6.76		7.33	
0l/1l	4.33		10.33		15.16		6.14			12.75		6.69		13.11
01/13		10.33		15.16		6.14		3.85	4.47		6.92		21.14	
02/15	10.27		12.10		3.69		2.22			8.59		8.38		6.82
02/17		9.43		9.01		5.97		4.37	8.05		13.11		7.82	

Table 12. Ammonium excretion rates (ug NH4/hr/kg fish) for the fourteen experimental groups of chinook salmon calculated at the middle of month of rearing.

Rearing year, date	Ammonium Excretion Rates (ug NH4/hr/kg fish)													
	A1	A2	B1	B2	C1	C2	D1	D2	E1	E2	F1	F2	G1	G2
1990-1991														
08/19	17.10		16.77		14.12		21.27		19.83		59.08		55.71	
09/16	6.73		7.06		5.47		3.28		5.31		19.65		9.51	
10/14	9.29		9.81		5.77		4.58		5.14		10.71		17.04	
11/11	11.74		7.82		5.31		8.78		8.95		14.73		11.40	
12/16	5.58		4.20		6.58		7.66		8.95		13.71		6.62	
01/20	4.56		0.00		3.85		2.51		4.32		7.26		9.41	
02/17	8.06		5.92		10.23		8.95		10.49		20.74		9.37	
1991-1992														
08/20	37.10	32.98	12.04	44.78	26.48	40.29	23.34	36.26	34.56	36.60	77.34	116.17	50.52	35.94
09/17	10.72	27.44	18.01	42.20	14.86	14.35	16.18	17.93	16.43	9.10	38.53	25.38	31.19	27.77
10/15	14.22	14.13	24.14	11.48	16.85	12.58	17.45	11.82	12.55	7.15	22.79	28.39	27.44	1.22
11/19	6.21	10.27	1.46	9.66	13.16	3.68	6.40	6.02	7.82	9.52	13.72	22.46	7.91	9.91
12/10	11.31		6.93		3.92		4.01		11.69		14.17		17.25	
12/17		3.98		4.63		4.31		4.31		10.06		4.74		8.67
01/14	2.89	5.21	5.11	7.42	2.92	5.70	2.91	2.81	4.84	5.28	8.04	6.21	8.22	7.53
02/11	12.55	9.09	11.99	11.41	8.28	6.92	10.58	6.77	13.50	7.98	12.81	3.33	21.08	12.91
1992-1993														
08/25	39.29		29.79		34.27		29.33		--		--		--	
08/27		46.19		45.09		16.11		31.54		33.76		33.50		62.76
09/15	20.75		13.32		12.03		13.98		10.84		18.86		5.27	
09/17		22.27		26.17		12.29		11.25		20.43		18.83		25.60
10/13	13.61		18.22		12.47		11.97		10.76		13.45		11.63	
10/15		13.15		14.40		8.31		11.68		15.27		6.00		17.22

Table 13. Results from analysis of variance for ammonium excretion rates estimated at midmonth intervals from experimental raceways for single rearing years. Values are calculated from the data shown in Table 12.

Year,	Deg.Freed.	F	$F_{0.95}$	
1990-1991	6, 42	1.963	2.34	N. S.
1991-1992				
Series 1	6 42	1.556	2.34	N. S.
Series 2	6, 42	0.741	2.34	N. S.
1992-1993				
Series 1	6 42	0.216	2.34	N. S.
Series 2	6 42	0.485	2.34	N. S.
1993-1994				
Series 1	6, 42	0.475	2.34	N. S.
Series 2	6, 42	0.735	2.34	N. S.

While the sampling was not designed to be tested statistically (replicate ponds were not sampled), graphic analysis of the total amount of ammonium excreted over a 24-hour period clearly showed differences between ponds (Fig. 27). When excretion rates were corrected for the kg of fish in each raceway, results indicated (Fig. 28) that the fish in the second and third passes of the Michigan ponds excreted ammonium at much greater rates than those from the raceways. In group D of the raceways (triple density), excretion was much higher than that of the other raceways. The fish reared at higher densities seemed to respond to elevated average concentrations of ammonium in the raceways (Fig. 29). Thus, ammonium excretion rates in the first pass of the Michigan ponds (group E) was similar to that from the raceways (groups A, B, and C), whereas the AER from the second pass (group F), which experienced the combined excretion of groups E and F, had excretion rates much higher than that of group E. AERs were highest in the third pass Michigan pond (group G), where the waste from all three groups (groups E, F. and G) had accumulated.

When AERs were plotted against load (kg/Lpm) of the fish in each of the groups (Fig. 30), a correlation coefficient (R^2) of 0.337 was obtained. Because AER was calculated using the number of kg of fish per raceway, it was expected that there would be no significant relationship. The significant relationship obtained ($t = 1.59$, $t_{0.95} = 2.57$, df 5) suggested that increased load resulted in increased AERs, especially in the Michigan ponds.

Because the excretion rates were highest during September due to the warm water, it was expected that this would provide

Figure 27. Total mg ammonium excreted per day from each of the experimental raceways sampled on September 7-8, 1993. .

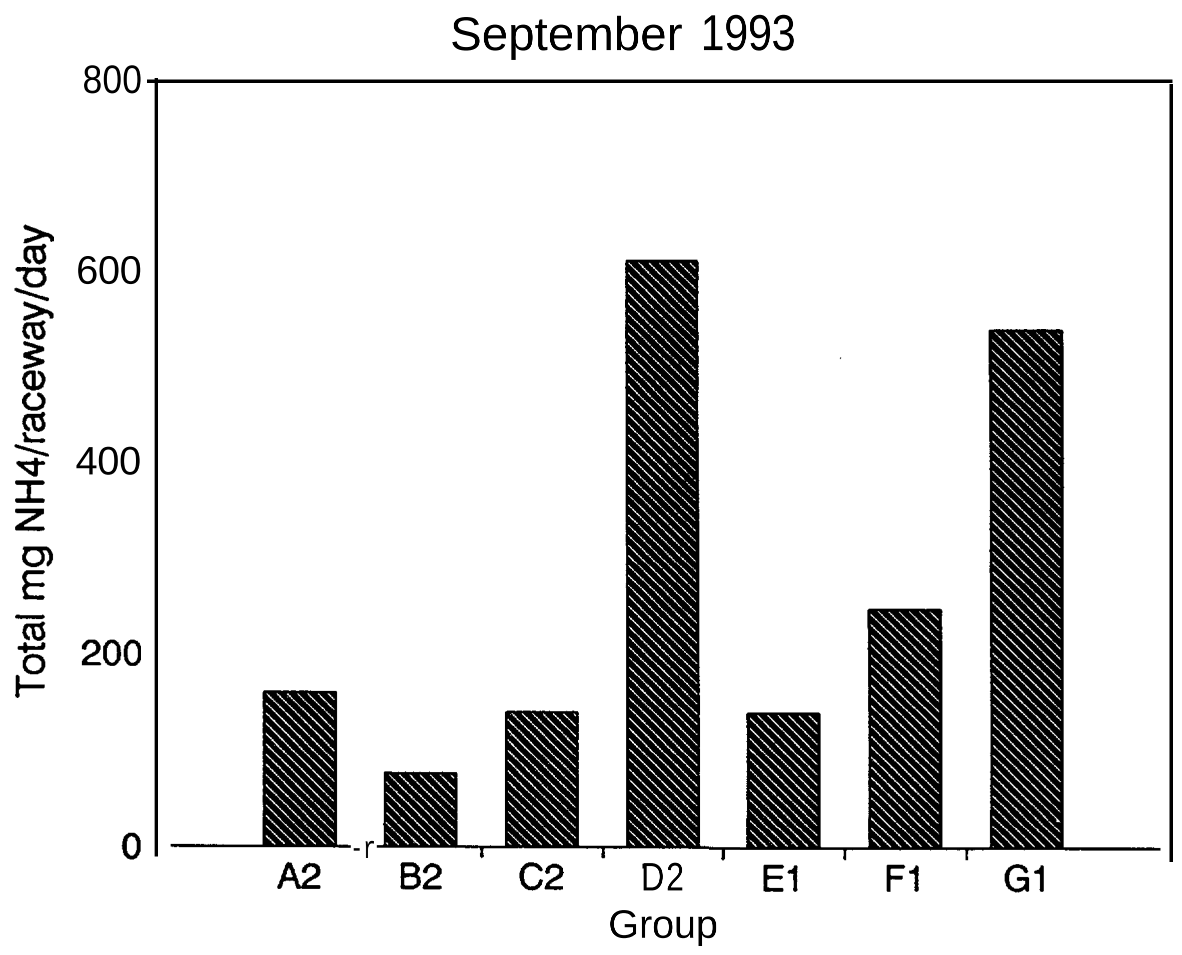

September 1993
Total mg NH4/raceway/day
800
600
400
200
0
A2
B2
C2
D2
E1
F1
G1
Group

Figure 28. Total ug of ammonium excreted per day per kilogram of fish for experimental raceways sampled on September 7-8, 1993.

September 1993

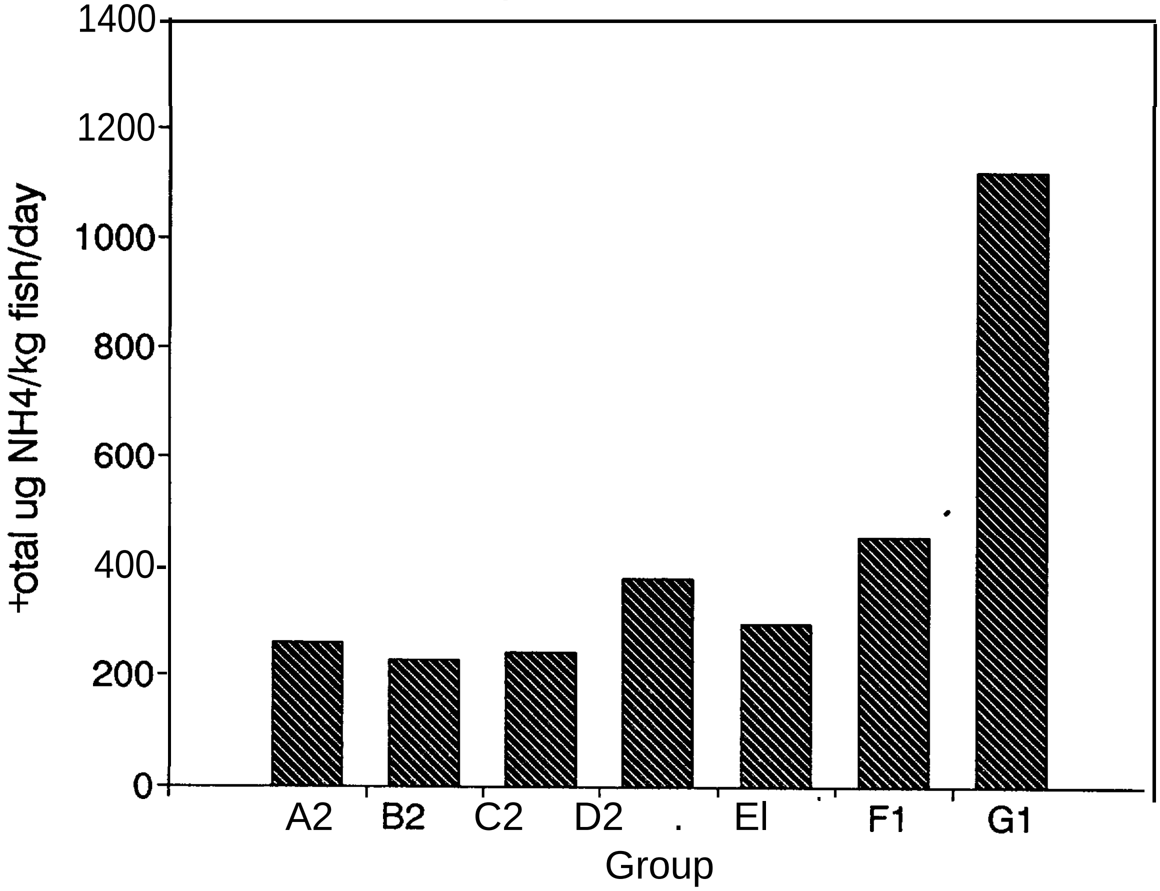


Figure 29. Average ammonium concentrations (ug/ml) for experimental raceways measured during a 24-hour period on September 7-8, 1993.

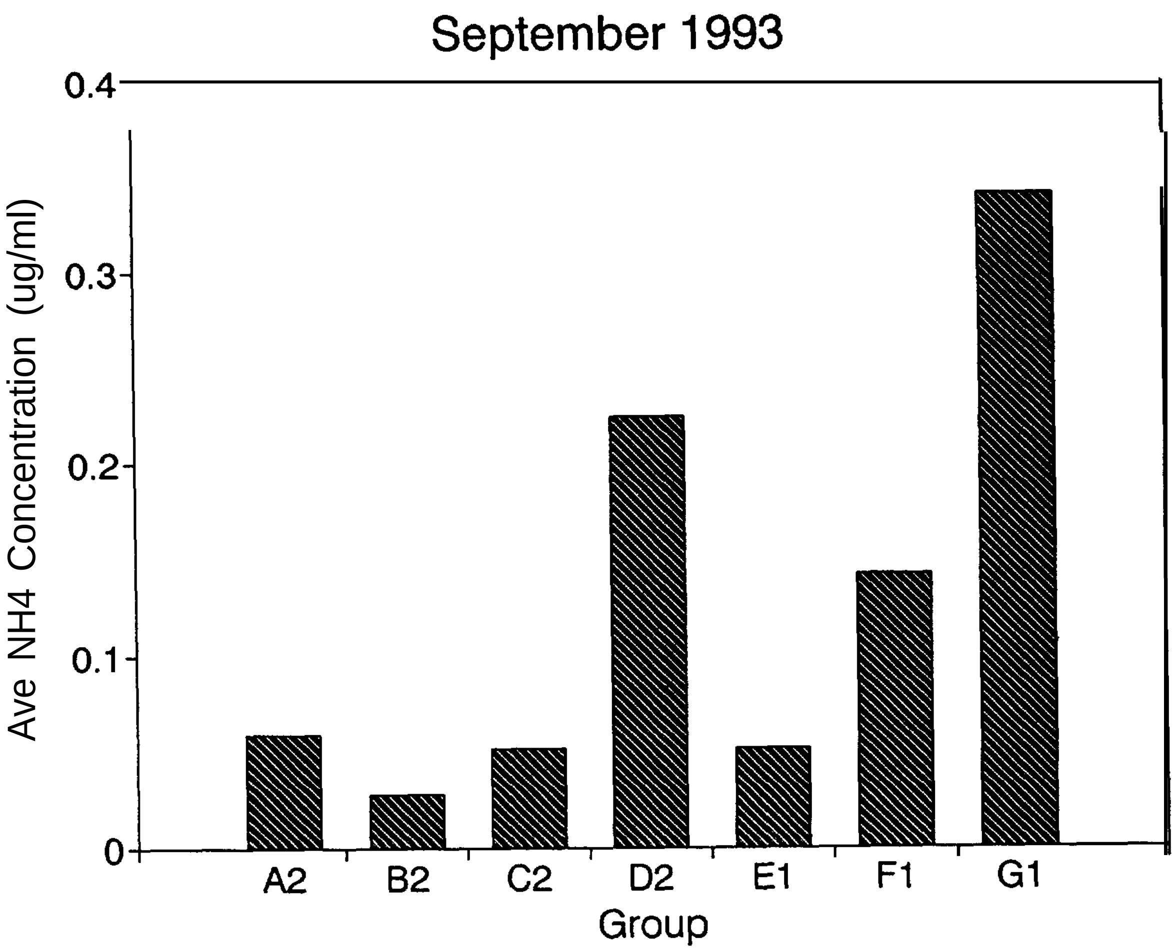
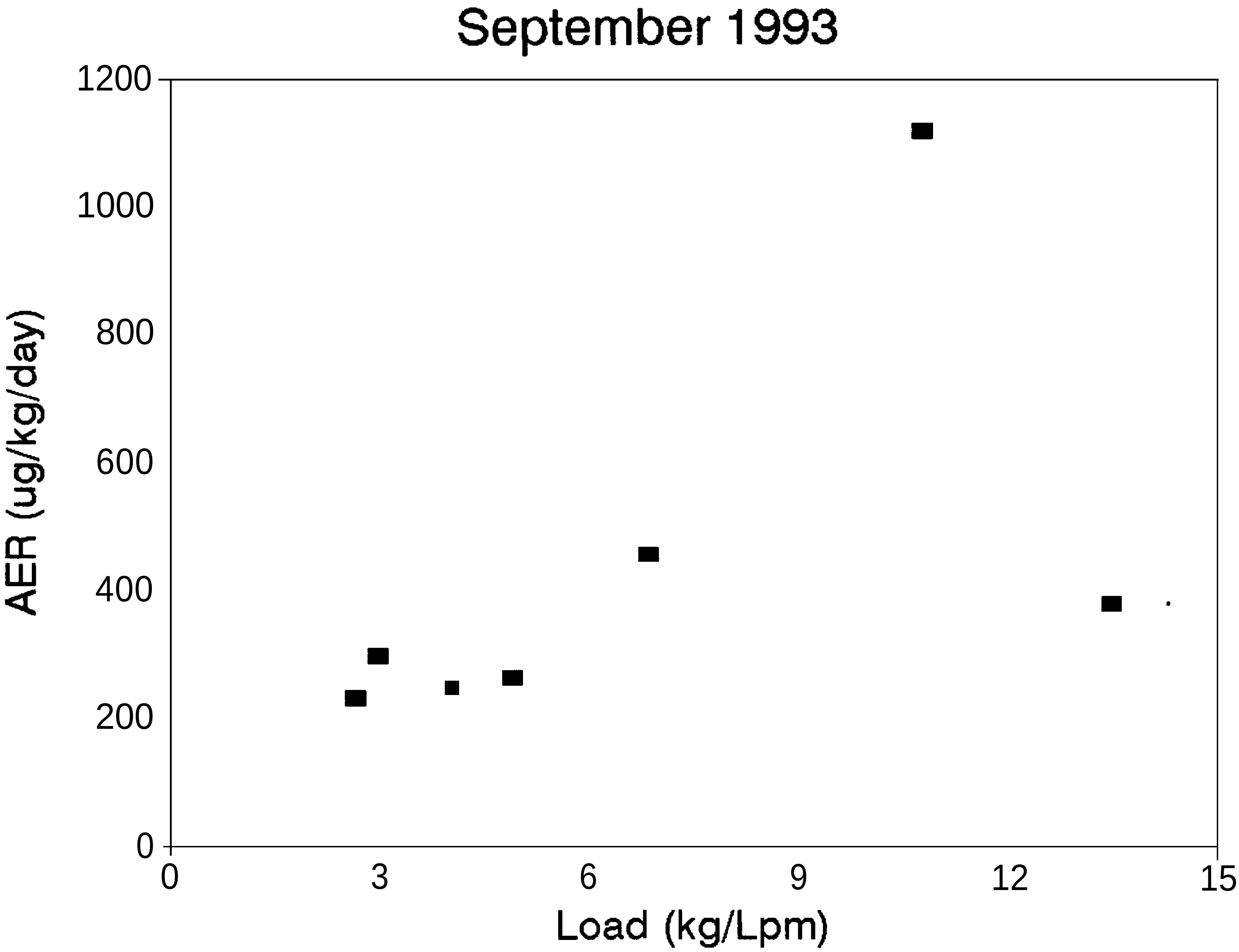

September 1993
0.4
0.3
0.2
0.1
0
Ave NH4 Concentration (ug/ml)
A2
B2
C2
D2
E1
F1
G1
Group

Figure 30. Relationship between AER and load in the seven experimental raceways sampled on September 7-8, 1993.



September 1993
AER (ug/kg/day)
1200
1000
800
600
400
200
0
0
3
6
9
12
15
Load (kg/Lpm)

the most sensitive test of the differences in ammonium excretion with rearing density. However, other time points (December, February, and March) were examined as well. Results are shown in Table 14. Inspection of Table 14 shows that, in most cases, AERs from fish in Michigan ponds was nearly twice that of the fish reared in raceways.

The biochemical mechanism for stimulation of AER by the presence of high levels of ammonium is not clear. A number of other changes occur in these ponds, including decreases in pH. However, these changes in AER in the Michigan ponds are some of the most dramatic differences between fish reared in raceways and those reared in Michigan ponds. These data, together with other factors such as size and disease history, may help to explain the reduction of survival to adulthood of fish released from these ponds.

Unionized Ammonia Concentrations in Experimental Ponds

Analyses to this point have considered the total levels of ammonium measured in the raceway as ammonium ion. However, the nature of the primary excretory product in fish is not yet clear. Some hypotheses consider that NH_4^+ is excreted across the gill as a counter-ion in (Na+K)-ATPase in exchange for Na^+. Other hypotheses suggest that NH_3 diffuses across the gill membrane as a gas and is subsequently protonated to form NH_4^+, which cannot pass back through the membrane because of its charge. Regardless of which hypothesis is correct, excretory

Table 14. Total mg NH4 excretion per pond per day, AER (ug NH_4/kg fish/day) and average ammonium level (ug/L) in experimental ponds measured hourly in March, September, and December 1993 and February 1994.

Date, group	Total NH_4[a] (mg/pond/day)	AER[b] (ug/kg/day)	Ave Conc[c] (ug/L)	Load[d] (lb fish/gpm)
March 1993				
A2	89.9	61.9	0.033	7.69
B2	76.6	81.0	0.028	4.16
c2	96.5	49.7	0.035	8.13
D2	265.7	52.6	0.097	21.97
El	224.3	106.8	0.055	4.71
F1	265.7	114.8	0.120	5.63
G1	265.7	117.5	0.185	6.10
September 1993				
A2	159.5	261.4	0.058	4.86
B2	75.9	230.5	0.028	2.70
c2	140.4	244.0	0.051	3.18
D2	612.0	379.4	0.224	13.36
El	140.5	296.5	0.051	2.76
F1	248.0	453.9	0.142	3.87
G1	541.0	1120.5	0.341	4.20
December 1993				
A2	76.1	68.5	0.028	4.86
B2	64.6	112.0	0.023	2.70
c2	37.5	34.5	0.014	3.18
D2	161.3	51.9	0.059	13.36
El	181.1	149.9	0.044	2.76
F1	152.0	100.4	0.081	3.87
G1	221.0	158.3	0.135	4.20
February 1994				
A2	30.8	29.3	0.011	4.86
B2	25.1	38.5	0.0095	2.70
c2	46.7	40.5	0.017	3.18
D2	85.8	27.5	0.031	13.36
El	52.6	51.0	0.013	2.76
F1	77.4	54.7	0.032	3.87
G1	88.7	57.2	0.053	4.20

[a]Refers to the total output from the raceway for a 24-hour period.
[b]Ammonium excretion rate corrected for the total kg of fish in the raceway at the time of the experiment.
'Average concentration of ammonium in the raceway over a 24-hour period.
[d]Load in each experimental raceway at the end of the experimental rearing.

ammonia immediately distributes according to the equation:

$$NH_4^+ \rightleftharpoons NH3 + H+ \qquad (12)$$

with a K_{eq} which is dependent upon both temperature and pH (Emerson et al. 1975.). NH3 is considered to be the toxic species (Wuhrmann et al., 1947) while NH_4^+ is considered to be rather non-toxic to fish (Tabata 1962).

Several tables have been published providing the concentrations of NH3 with different pHs and temperatures but are of widely different quality. Burrows (1964) published a table for a narrow range of pH and temperature which was subsequently found to be inaccurate. No details of his calculations were presented. Trussell (1972) produced a larger table but used a graphical method which produced less accurate results than were possible with computer analysis. Montgomery and Stiff (1971) published a nomogram for determining the fraction of NH3 at a given pH and temperature but his equilibrium constants were subject to error. Skarheim (1973) published an extensive table which related percent NH3 to pH, temperature, and dissolved solids, but provided little information on how he had made his calculations. Emerson et al. (1975) used the data of Bates and Pinching (1949) to model the behavior of the equilibrium constant in relation to pH and temperature. They found that the equilibrium constant followed the equation:

$$pK = 0.09018 + 2729.92/T \qquad (13)$$

where pK is the negative log of the dissociation constant and T is temperature in ^{o}C. They then used the formula:

$$f = 1/(10^{pK-pH} + 1) \qquad (14)$$

to determine the fraction of NH_3 at a given temperature and pH. We have used these equations in the following analyses.

Temperatures and pH measurements at each of the samples taken during the rearing cycles from 1990 to 1994 are presented in Appendix C. Using these values of temperature and pH, it is possible to calculate the amounts of NH_3 present in the raceways from the data in Appendix B. These data are presented in Table 15. Superficially, the data in Table 15 look similar to those presented in Appendix B. However, the data in Appendix B are raw data from analyses of ammonium content in ug/L for raceways throughout the rearing period, while the data in Table 15 are unionized ammonia excretion rates (ug NH_3/hr/kg fish) (UAERS). Within the pH and temperature ranges given in Appendix C, unionized ammonia concentrations (in ug/mL) were between l/100 and l/1000 the values shown in Appendix B.

The levels of unionized ammonia presented in Table 15 represent the highest levels attained in each of the raceways, since the values were calculated from the concentrations of ammonium at the outflow of each raceway. The average concentration of unionized ammonia in each raceway is approximately half the values presented in Table 15.

UAERs tended to vary with temperature and season similar to the levels of total ammonium (Figs. 31 and 32). Because the UAERs were derived from AERs, results from analyses for AERs would also apply to the UAERs. Consequently, analysis of the effects of load and temperature on UAERs were not performed.

Table 15. Unionized ammonia excretion rates (micrograms NH_3/hr/kg fish) for experimental raceways at Willamette Hatchery, 1990-1994.

Year, date	A1	A2	B1	B2	C1	C2	D1	D2	E1	E2	F1	F2	G1	G2
1990-1991 Rearing Year														
09/23/90	0.017		0.063		0.017		0.008		0.044		0.049		0.021	
09/30/90	0.026		0.000		0.023		0.004		0.037		0.068		0.015	
10/07/90	0.019		0.022		0.012		0.010		0.010		0.034		0.011	
10/14/90	0.073		0.099		0.043		0.017		0.048		0.057		0.055	
10/28/90	0.004		0.022		0.012		0.010		0.013		0.012		0.023	
11/04/90	0.006		0.005		0.004		0.006		0.020		0.026		0.004	
11/11/90	0.035		0.028		0.015		0.017		0.015		0.028		0.018	
11/18/90	0.000		0.000		0.012		0.010		0.025		0.069		0.044	
11/25/90	0.019		0.023		0.016		0.020		0.033		0.023		-0.012	
12/02/90	0.048		0.049		0.027		0.018		0.033		0.032		0.028	
12/09/90	0.031		0.017		0.033		0.010		0.023		0.023		0.016	
12/16/90	0.021		0.020		0.023		0.021		0.032		0.040		0.018	
12/23/90	0.025		0.025		0.013		0.019		-0.003		0.020		0.016	
12/30/90	0.016		0.032		0.019		0.014		0.027		0.040		0.024	
01/06/91	0.009		0.009		0.005		0.005		0.005		0.009		0.011	
01/13/91	0.000		0.000		0.003		0.005		0.008		-0.004		0.008	
01/20/91	0.018		0.000		0.015		0.005		0.013		0.012		0.010	
01/27/91	0.004		00.13		0.002		0.004		0.035		0.007		0.014	
02/03/91	0.013		0.018		0.019		0.013		0.013		0.012		0.005	
02/10/91	0.019		0.010		0.008		0.002		0.034		0.051		0.006	
02/17/91	0.028		0.025		0.029		0.008		0.036		0.034		0.007	
1991-1992 Rearing Year														
08/06/91	0.249	0.358	0.278	0.448	0.531	0.268	0.258	0.337	0.197	0.298	0.465	0.810	0.609	0.394
08/13/91	--	0.408	--	0.617	--	0.375	--	0.229	0.411	--	0.459	--	0.078	--
08/20/91	0.393	0.429	0.157	0.617	0.234	0.375	0.140	0.222	0.527	0.362	0.569	0.749	0.258	0.175
08/27/91	0.310	0.421	0.391	0.638	0.273	0.451	0.125	0.196	0.527	0.139	0.298	0.160	0.108	0.142
09/03/91	0.234	0.398	0.405	0.533	0.220	0.333	0.038	0.161	0.304	0.235	0.245	0.297	0.172	0.070
09/10/91	0.325	0.263	0.239	0.328	0.379	0.241	0.143	0.115	0.258	0.236	0.452	0.527	0.150	0.072
09/17/91	0.109	0.334	0.229	0.601	0.109	0.130	0.084	0.074	0.229	0.145	0.259	0.219	0.118	0.155
09/24/91	0.274	--	0.303	--	0.145	--	0.087	--	--	0.222	--	0.526	--	0.128
10/01/91	0.162	0.241	0.273	0.371	0.150	0.152	0.074	0.101	0.184	0.204	0.225	0.393	0.066	0.073
10/08/91	0.164	0.087	0.202	0.114	0.136	0.216	0.078	0.112	0.144	0.280	0.147	0.413	0.064	0.056

Table 15 (cont.). Unionized ammonia excretion rates (micrograms NH_3/hr/kg fish) for experimental raceways at Willamette Hatchery, 1990-1994.

Year, date	A1	A2	B1	B2	C1	C2	D1	D2	E1	E2	F1	F2	G1	G2
1991-1992 Rearing Year														
10/15/91	0.117	0.153	0.239	0.156	0.116	0.111	0.079	0.417	0.111	0.076	0.106	0.166	0.079	0.005
10/22/91	0.070	0.063	0.103	0.146	0.073	0.081	0.040	0.026	0.051	0.101	0.041	0.137	0.028	0.057
10/29/91	--	--	--	--	--	--	--	--	--	--	--	--	--	--
11/12/91	0.017	0.040	0.030	0.080	0.018	0.033	0.007	0.019	0.052	0.035	0.045	0.031	0.022	0.014
11/19/91	0.032	0.032	0.009	0.037	0.057	0.011	0.019	0.013	0.034	0.054	0.051	0.081	0.018	0.023
11/26/91	--	0.023	--	0.036	--	0.009	--	0.011	--	0.037	--	0.019	--	0.014
12/03/91	0.026	0.029	0.054	0.035	0.025	0.022	0.013	0.017	0.021	0.063	0.025	0.052	0.033	0.025
12/10/91	0.040	0.031	0.037	0.026	0.012	0.014	0.010	0.012	0.051	0.051	0.045	0.040	0.037	0.016
12/17/91	--	0.015	--	0.020	--	0.015	--	0.011	--	0.046	--	0.017	--	0.020
12/24/91	0.019	--	0.027	--	0.009	--	0.012	--	0.019	--	0.032	--	0.081	--
12/31/91	0.034	0.023	0.029	0.024	0.011	0.007	0.008	0.008	0.024	0.050	0.044	-0.006	0.009	0.012
01/07/92	0.029	0.036	0.023	0.035	0.012	0.017	0.007	0.008	0.034	0.026	0.014	0.024	0.024	0.004
01/14/92	0.015	0.025	0.029	0.041	0.013	0.025	0.009	0.009	0.022	0.037	0.027	0.021	0.019	0.018
01/21/92	0.016	0.027	0.022	0.034	0.007	0.020	0.005	0.009	0.042	0.037	0.021	-0.016	0.013	0.008
01/28/92	0.031	0.049	0.028	0.096	0.021	0.041	0.011	0.017	0.046	0.088	0.062	0.060	0.024	0.028
02/04/92	0.010	0.024	0.017	0.024	0.014	0.015	0.009	0.012	0.053	0.058	0.023	0.043	0.033	0.031
02/11/92	0.060	0.053	0.067	0.084	0.034	0.039	0.030	0.027	0.091	0.076	0.057	0.020	0.055	0.049
02/18/92	0.023	--	0.041	--	0.024	--	0.010	--	0.031	--	0.019	--	0.015	--
02/25/92	0.034	--	0.040	--	0.029	--	0.006	--	0.034	--	0.021	--	0.014	--
1992-1993 Rearing Year														
08/04/92	0.773	--	0.508	--	0.316	--	0.182	--	--	--	--	--	--	--
08/11/92	0.306	--	0.723	--	0.212	--	0.085	--	0.165	--	0.332	--	0.224	--
08/25/92	0.339	--	0.323	--	0.247	--	0.164	--	--	--	--	--	--	--
08/27/92	--	0.490	--	0.548	--	0.152	--	0.202	--	0.631	--	0.355	--	0.462
09/01/92	0.161	--	0.095	--	0.069	--	0.145	--	0.362	--	0.305	--	0.270	--
09/03/92	--	0.359	--	0.412	--	0.140	--	0.164	--	0.874	--	0.212	--	0.157
09/08/92	0.156	--	0.045	--	0.091	--	0.094	--	0.288	--	0.189	--	0.204	--
09/10/92	--	0.176	--	0.226	--	0.056	--	0.110	--	0.669	--	0.317	--	0.150
09/15/92	0.119	--	0.096	--	0.059	--	0.054	--	0.148	--	0.118	--	0.022	--
09/17/92	--	0.172	--	0.211	--	0.084	--	0.066	--	0.272	--	0.170	--	0.164
09/22/92	0.234	--	0.271	--	0.133	--	0.100	--	0.192	--	0.097	--	0.170	--
09/24/92	--	0.088	--	0.086	--	0.034	--	0.036	--	0.125	--	0.083	--	0.088
10/01/92	--	--	--	0.115	--	0.044	--	0.040	--	0.167	--	0.103	--	0.134
10/06/92	0.044	--	0.035	--	0.036	--	0.023	--	--	--	--	--	--	--
10/08/92	--	0.077	--	0.087	--	0.042	--	0.040	--	0.156	--	0.062	--	0.059

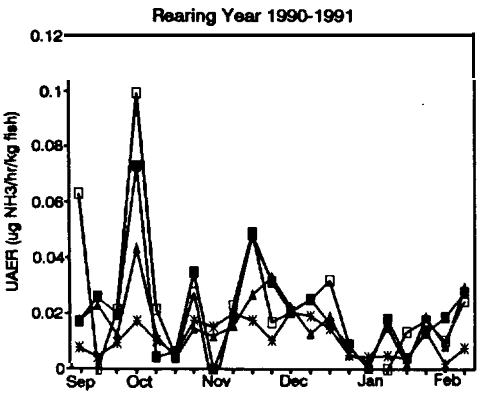
Table 15 (cont.). Unionized ammonia excretion rates (micrograms NH_3/hr/kg fish) for experimental raceways at Willamette Hatchery, 1990-1994.

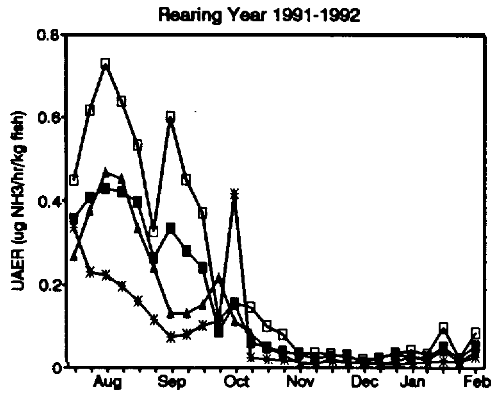
Year, date	A1	A2	B1	B2	C1	C2	D1	D2	E1	E2	F1	F2	G1	G2
1992-1993 Rearing Year														
10/13/92	0.045	--	0.074	--	0.038	--	0.029	--	0.056	--	0.040	--	0.024	--
10/15/92	--	0.064	--	0.114	--	0.036	--	0.048	--	0.105	--	0.034	--	0.082
10/20/92	0.025	--	0.039	--	0.017	--	0.028	--	0.063	--	0.141	--	0.038	--
10/22/92	--	0.050	--	0.066	--	0.030	--	0.029	--	0.062	--	0.065	--	0.058
10/27/92	0.026	--	0.031	--	0.024	--	0.024	--	0.041	--	0.028	--	0.041	--
10/29/92	--	0.026	--	0.034	--	0.024	--	0.027	--	0.055	--	0.049	--	0.032
11/03/92	0.019	--	0.006	--	0.011	--	0.013	--	0.057	--	0.052	--	0.016	--
11/05/92	--	0.017	--	0.016	--	0.012	--	0.014	--	0.039	--	0.043	--	0.027
11/10/92	0.021	--	0.027	--	0.026	--	0.015	--	0.014	--	0.025	--	0.006	--
11/12/92	--	0.025	--	0.040	--	0.020	--	0.019	--	0.058	--	0.040	--	0.021
11/17/92	0.019	--	0.030	--	0.015	--	0.019	--	0.042	--	0.005	--	0.026	--
11/19/92	--	0.013	--	0.033	--	0.008	--	0.007	--	0.018	--	0.017	--	0.005
11/24/92	0.007	--	0.007	--	0.007	--	0.005	--	0.071	--	0.008	--	0.005	--
12/01/92	0.012	--	0.024	--	0.016	--	0.006	--	0.014	--	0.023	--	0.015	--
12/03/92	--	0.010	--	0.009	--	-0.005	--	0.006	--	0.017	--	0.017	--	0.006
02/02/93	0.016	--	0.004	--	0.005	--	0.009	--	0.013	--	0.016	--	0.010	--
02/04/93	--	0.013	--	0.003	--	0.007	--	0.009	--	0.019	--	0.015	--	0.007
02/09/93	0.014	--	0.014	--	0.019	--	0.008	--	0.027	--	0.027	--	0.012	--
02/11/93	--	0.011	--	0.020	--	0.009	--	0.004	--	0.013	--	0.014	--	0.016
02/16/93	0.014	--	0.006	--	0.009	--	0.005	--	0.020	--	0.015	--	0.021	--
02/18/93	--	0.004	--	0.006	--	0.004	--	0.002	--	0.011	--	0.009	--	0.006
03/02/93	0.005	--	0.000	--	0.006	--	0.009	--	--	--	--	--	--	--
03/04/93	--	0.014	--	0.019	--	0.007	--	0.007	--	0.018	--	0.009	--	0.015
03/09/93	0.006	--	0.014	--	0.007	--	0.005	--	0.002	--	0.013	--	0.013	--
1993-1994 Rearing Year														
08/03/93	0.306	--	0.339	--	0.116	--	0.304	--	0.334	--	0.989	--	0.152	--
08/05/93	--						--							
08/10/93	0.272	0.339	0.331	0.292	0.196	0.153	0.093	0.266	0.197	0.145	0.264	0.232	0.189	0.483
08/12/93	--	--	--		--		--	--	--				--	
08/17/93	0.675	0.432	0.642	0.512	0.343	0.414	0.185	0.364	0.522	0.481	0.382	0.581	0.490	0.654
08/24/93	--	[illegible]	--	0.225	--	0.267	--	[illegible]	--	[illegible]	--	0.567	--	0.447
08/26/93	0.183	0.252	0.237	0.282	0.093	0.141	0.071	0.105	[illegible]	0.241	0.283	0.267	0.142	0.283
	--		--		--		--							
08/31/93	0.432	--	0.422	--	0.105	--	0.052	--	0.209	--	0.259	--	0.193	--
09/02/93	--	0.230	--	0.178	--	0.132	--	0.129	--	0.483	--	0.000	--	0.258
												--		
09/09/93	[illegible]	--	0.502	--	[illegible]	--	0.150	--	[illegible]	--	0.349	0.302	[illegible]	--
09/14/93	0.136	0.159	0.173	0.241	0.060	0.056	0.057	0.112	0.190	0.305	0.145	--	0.073	0.157
		--				--				--	--			--
09/16/93	--	0.153	--	0.152	--	0.104	--	0.050	--	0.176	0.000	0.079	--	0.091
09/21/93	0.037	--	0.033	--	0.028	--	0.019	--	0.075	--		--	0.078	--

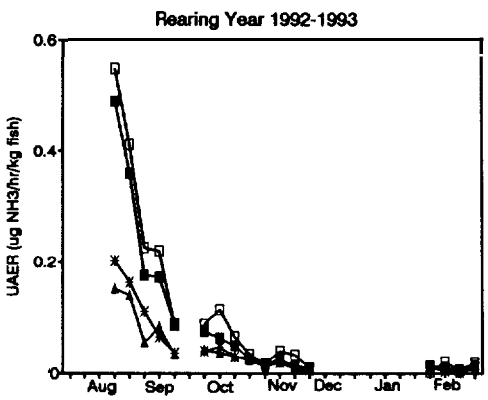
Table 15 (cont.). Unionized ammonia excretion rates (micrograms NH_3/hr/kg fish) for experimental raceways at Willamette Hatchery, 1990-1994.

Year, date	A1	A2	B1	B2	C1	C2	D1	D2	E1	E2	F1	F2	G1	G2
1993-1994 Rearing Year														
09/23/93	--	0.090	--	0.117	--	0.084	--	0.055	--	0.080	--	0.131	--	0.051
09/28/93	0.227	--	0.327	--	0.174	--	0.097	--	0.393	--	0.302	--	0.166	--
09/30/93	--	0.055	--	0.113	--	0.059	--	0.087	--	0.236		0.241	--	0.034
10/05/93	0.171	--	0.156	--	0.073	--	0.053	--	0.217	--	0.073	--	0.142	
10/07/93	--	0.077	--	0.113	--	0.054	--	0.073	--	0.139	--	0.095	--	0.106
10/12/93	0.138	--	0.128	--	0.048	--	0.032	--	0.089	--	0.136	--	0.075	--
10/14/93	--	0.078	--	0.111	--	0.037	--	0.047	--	0.176	--	0.072	--	0.070
10/19/93	0.050	--	0.062	--	0.028	--	0.021	--	0.045		0.055	--	0.034	--
10/21/93	--	0.098	--	0.070	--	0.096	--	0.040	--	0.140	--	0.052	--	0.082
10/26/93	0.095	--	0.108	--	0.050	--	0.021	--	0.077		0.099	--	0.027	--
10/28/93	--	0.116	--	0.124	--	0.084	--	0.039	--	0.153	--	0.050	--	0.054
11/02/93	0.042	--	0.028	--	0.005	--	0.011	--	0.056	--	0.027	--	0.043	--
11/04/93	--	0.030	--	0.034	--	0.040	--	0.024	--	0.038	--	0.037	--	0.070
11/09/93	0.026	--	0.000	--	0.031	--	0.015	--	0.024		0.033	--	0.011	--
11/11/93	--	0.023	--	0.027	--	0.012	--	0.012	--	0.100	--	0.015	--	0.024
11/16/93	0.068	--	0.089	--	0.041	--	0.029	--	0.055		0.065	--	0.012	
11/18/93	--	0.032	--	0.062	--	0.042	--	0.010	--	0.088	--	0.064	--	0.007
11/23/93	0.012	--	0.000	--	-0.005	--	0.005	--	0.047	--	0.037	--	0.013	--
11/25/93	--	0.014	--	0.019	--	0.014	--	0.023	--	0.022	--	0.056	--	0.005
11/30/93	0.031	--	0.000	--	0.005	--	0.014		0.052	--	0.029	--	0.032	--
12/02/93	--	0.025	--	0.033	--	0.039	--	0.014	--	0.055	--	0.040	--	0.033
12/08/93	0.026	--	0.022	--	0.020	--	0.013	--	0.067	--	0.013	--	-0.002	--
12/09/93		0.005	--	0.000	--	0.000	--	0.006	--	0.053	--	0.027	--	0.010
12/14/93	0.039	--	0.056	--	0.022	--	0.014		0.035	--	0.023	--	0.019	--
12/16/93	--	0.029	--	0.076		0.006	--	0.011	--	0.000	--	0.053	--	0.021
01/11/94	0.020	--	0.047	--	0.012	--	0.013	--	0.028	--	0.032	--	0.071	--
01/13/94	--	0.038	--	0.063	--	0.021	--	0.011	--	0.075	--	0.028	--	0.039
01/18/94	0.012	--	0.006	--	-0.004	--	0.000	--	0.025	--	0.010	--	0.015	--
01/20/94	--	0.014	--	0.048	--	0.021	--	0.014	--	0.056	--	0.016	--	0.023
01/25/94	0.040	--	0.038	--	0.000	--	0.008	--	0.041	--	0.049	--	0.041	--
01/27/94	--	0.017	--	0.012		0.017	--	0.013	--	0.018	--	0.026	--	0.006
02/01/94	0.006	--	0.009	--	0.000	--	0.000	--	0.010	--	0.012	--	0.004	--
02/03/94	--	0.004	--	0.048		0.015	--	0.011	--	0.050	--	0.039	--	0.000
02/08/94	0.029	--	0.020	--	0.009	--	0.005	--	0.041	--	0.041	--	0.021	--
02/10/94	--	0.043	--	0.000	--	0.007	--	0.009	--	0.019		0.023	--	0.000
02/15/94	0.069	--	0.085	--	0.025	--	0.013	--	0.078	--	0.096	--	0.043	--
02/17/94	--	0.069	--	0.069	--	0.044	--	0.027	--	0.091	--	0.068	--	0.041

Figure 31. UAERs (ug NH_3/hr/kg fish) measured at the outlets of raceways containing fish from groups A2 (-■-), B2 (-□-), C2 (-▲-), and D2 (-✱-) for four rearing years at Willamette Hatchery.


Rearing Year 1990-1991
UAER (ug NH3/hr/kg fish)
0.12
0.1
0.08
0.06
0.04
0.02
0
Sep Oct Nov Dec Jan Feb


Rearing Year 1991-1992
UAER (ug NH3/hr/kg fish)
0.8
0.6
0.4
0.2
0
Aug Sep Oct Nov Dec Jan Feb


Rearing Year 1992-1993
UAER (ug NH3/hr/kg fish)
0.6
0.4
0.2
0
Aug Sep Oct Nov Dec Jan Feb

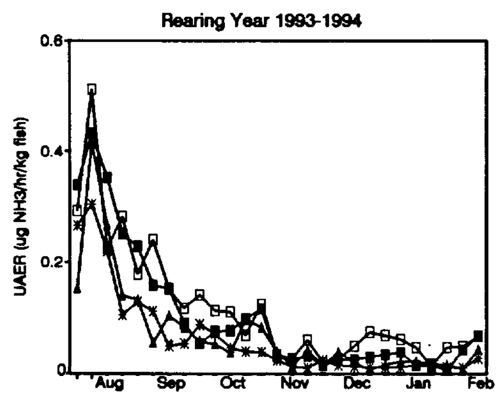
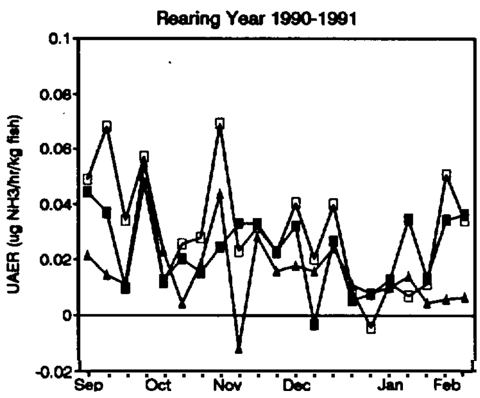
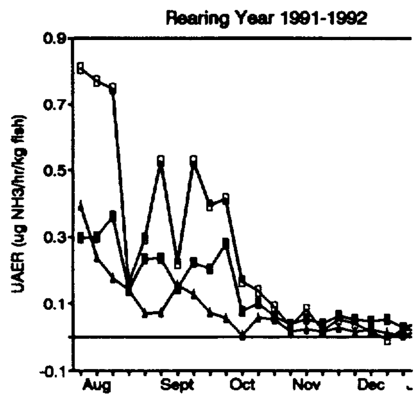
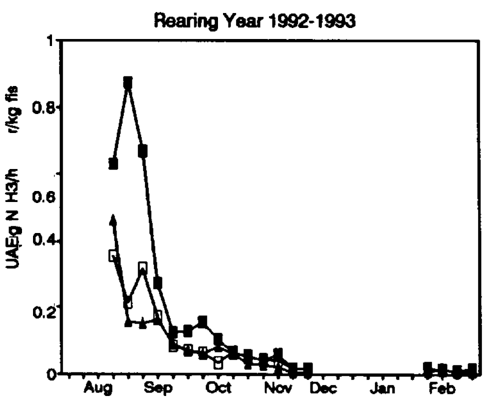
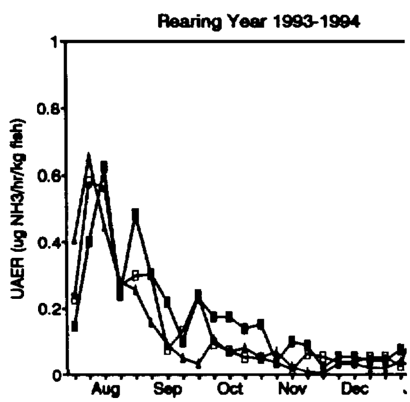

Rearing Year 1993-1994
UAER (ug NH3/hr/kg fish)
0.6
0.4
0.2
0
Aug Sep Oct Nov Dec Jan Feb

Figure 32. UAERs (ug NH3/hr/kg fish) measured at the outlets of raceways containing fish from groups El (-a-), Fl (-□ -), and G1 (-A-) for four rearing years at Willamette Hatchery.


Rearing Year 1990-1991
UAER (ug NH3/hr/kg fish)
0.1
0.08
0.06
0.04
0.02
0
-0.02
Sep
Oct
Nov
Dec
Jan
Feb


Rearing Year 1991-1992
UAER (ug NH3/hr/kg fish)
0.9
0.7
0.5
0.3
0.1
-0.1
Aug
Sept
Oct
Nov
Dec


Rearing Year 1992-1993
UAEg N H3/h r/kg fis
1
0.8
0.6
0.4
0.2
0
Aug
Sep
Oct
Nov
Dec
Jan
Feb

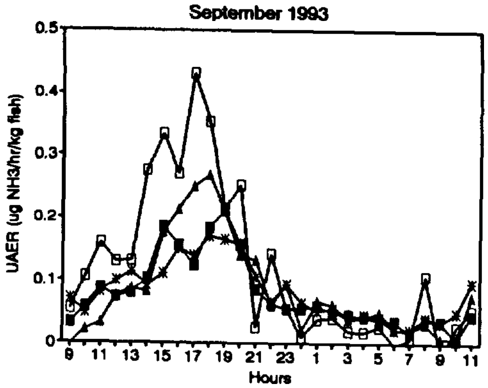

Rearing Year 1993-1994
UAER (ug NH3/hr/kg fish)
1
0.8
0.6
0.4
0.2
0
Aug
Sep
Oct
Nov
Dec

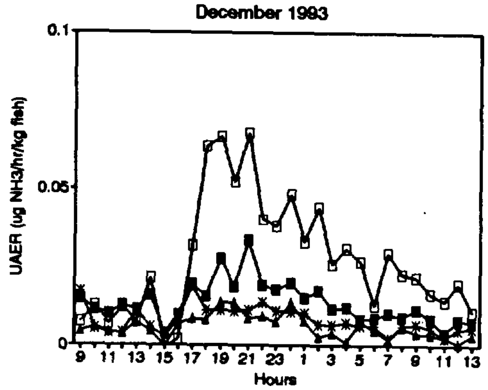
Die1 cycles of ammonium excretion were examined for the concentrations of unionized ammonia in more detail because daily excretion rates could be calculated from these studies. Concentrations of ammonia in experimental raceways showed die1 cycles similar to those of the ammonium ions. When excretion rates were calculated by incorporating flow and biomass, UAERs were obtained which also showed die1 cycles (Figs. 33 and 34). Some interesting differences were found between UAERs from fish in raceways and from those in Michigan ponds when these were sampled in September 1993. In raceways (Fig. 331, die1 cycles in UAER had a sharp maximum between 1700 and 1900 hours, approximately the time of maximum water temperature. Group B seem to have higher UAERs than groups A, C, or D. In the Michigan ponds, however, maximum UAERs seemed to be broader, more irregular, and somewhat later (1900-2300 hours) than those of fish reared in the raceways (Fig. 34). Maximum levels of UAERs were nearly twice those from fish reared in groups A, C or D.

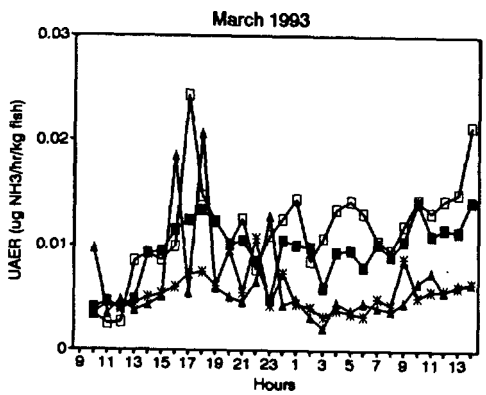
Because the concentrations for NH3 could be calculated over a 24-hour period on days of die1 sampling, it was possible to calculate the total NH3 excretion per day per pond, the total NH3 excretion per day per kg of fish, and the average NH3 concentration per pond during the day (Table 16).

Total NH3 excretion per pond per day was greatest in September when metabolic activity was highest and decreased to least levels in February (Fig. 35). Excretion was greatest in group D in September, when 3.3 mg NH3 was excreted. This amount

Fig. 33. Die1 cycles of UAERs (ug NH3/hr/kg fish) in raceways containing fish from groups A2 (-■-), B2 (-□-), C2 (-▲-), and D2 (-✱-) measured in September 1993, December 1993, March 1993, and February 1994.


September 1993
UAER (ug NH3/hr/kg fish)
0.5
0.4
0.3
0.2
0.1
0
9 11 13 15 17 19 21 23 1 3 5 7 9 11
Hours


December 1993
UAER (ug NH3/hr/kg fish)
0.1
0.05
0
9 11 13 15 17 19 21 23 1 3 5 7 9 11 13
Hours


March 1993
UAER (ug NH3/hr/kg fish)
0.03
0.02
0.01
0
9 11 13 15 17 19 21 23 1 3 5 7 9 11 13
Hours

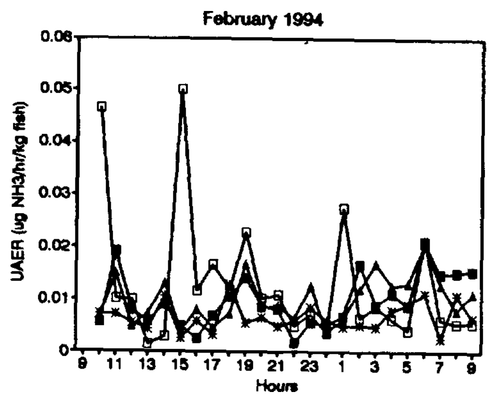
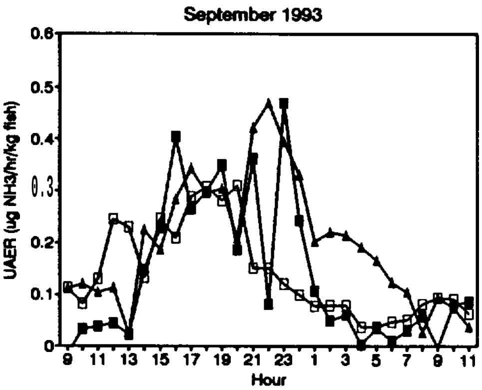
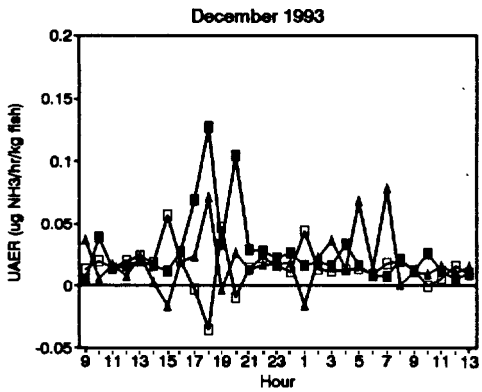
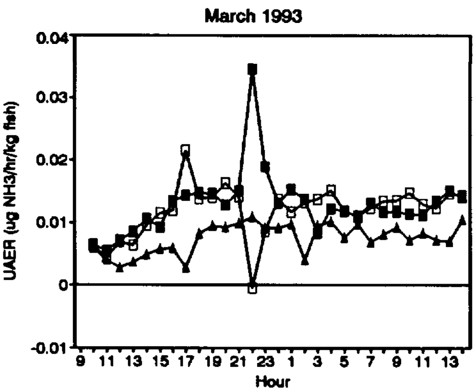

February 1994
UAER (ug NH3/hr/kg fish)
0.06
0.05
0.04
0.03
0.02
0.01
0
9 11 13 15 17 19 21 23 1 3 5 7 9
Hours

Fig. 34. Die1 cycles of UAERs (ug NH_3/hr/kg fish) in raceways containing fish from groups El (-■-), F1 (-□-), and G1 (-▲-) measured in September 1993, December 1993, March 1993, and February 1994.


September 1993
UAER (ug NH3/hr/kg fish)
Hour


December 1993
UAER (ug NH3/hr/kg fish)
Hour


March 1993
UAER (ug NH3/hr/kg fish)
Hour

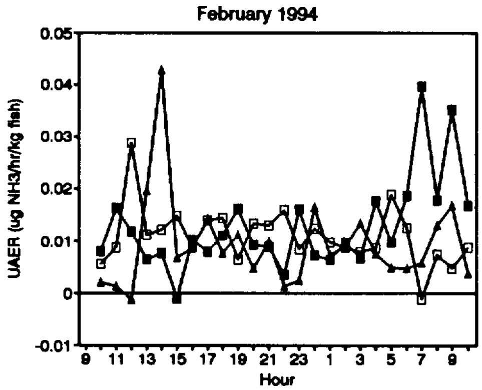
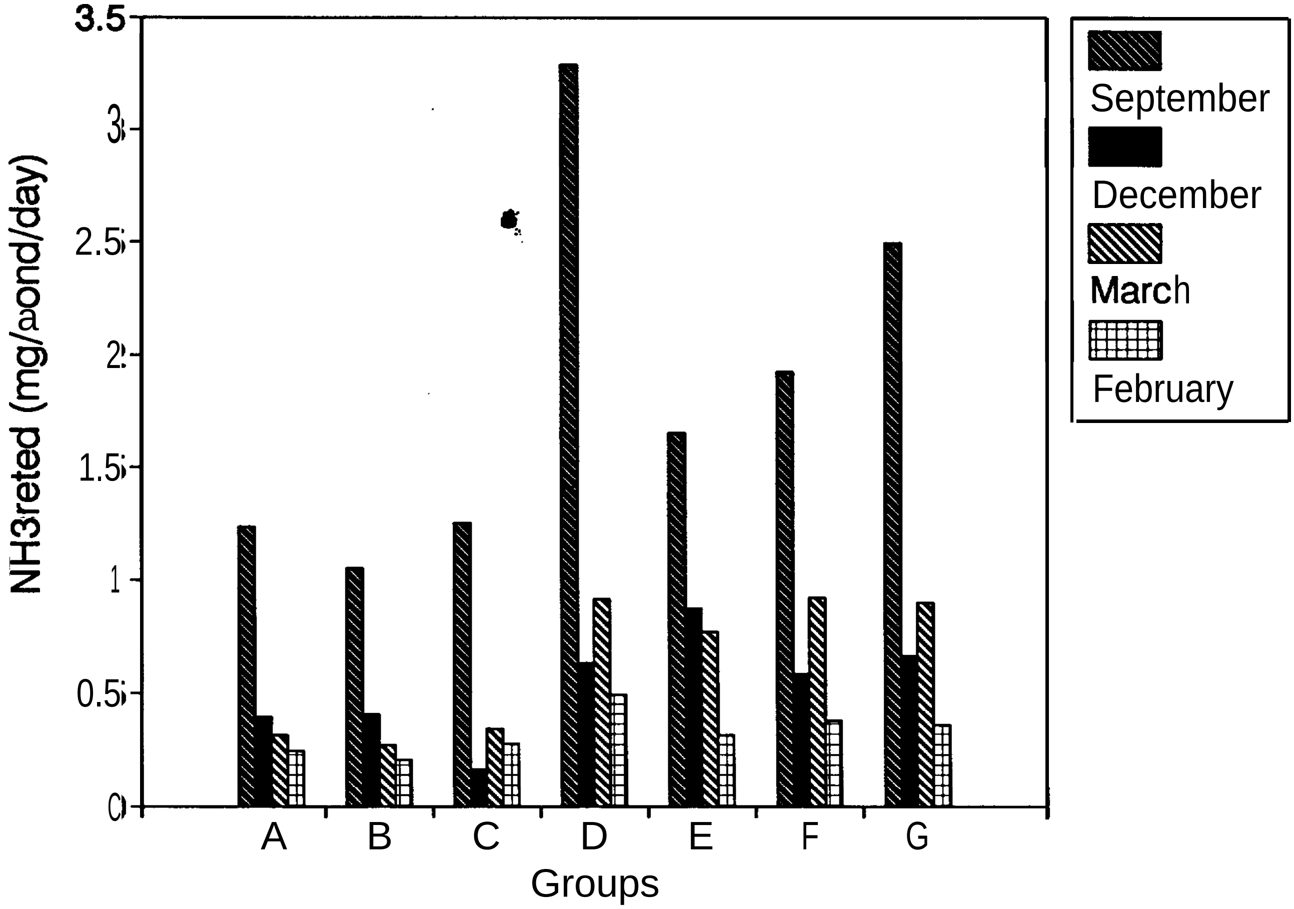

February 1994
UAER (ug NH3/hr/kg fish)
Hour

Table 16. Total output of unionized ammonia per kg fish per day, total output of unionized ammonia per raceway per day, average concentration of unionized ammonia in raceways, average pH's, and average temperatures for selected days in 1993 and 1994. Values were based on the sums or averages of hourly samples taken over a 24-hour period. Numbers represent the averages at the effluent end of the raceways.

Date, Group	Total Ammonia Excretion w/kg/day	mg/raceway/day	Ave. Conc ug/mL	Ave. Temp	Ave. PH
March 1993					
A2	0.207	0.301	0.00011	4.86[a]	7.43
B2	0.256	0.242	0.00009	4.86	7.40
c2	0.149	0.288	0.00011	4.86	7.38
D2	0.126	0.638	0.00023	4.86	7.28
El	0.306	0.643	0.00016	4.86	7.36
Fl	0.272	0.629	0.00015	4.86	7.28
Gl	0.173	0.391	0.00010	4.86	7.07
September 1993					
A2	2.051	1.258	0.00044	13.79	7.49
B2	3.226	1.060	0.00035	13.88	7.71
c2	2.178	1.250	0.00042	13.53	7.53
D2	2.067	3.338	0.00120	13.56	7.35
El	3.680	1.746	0.00028	13.68	7.65
Fl	4.245	2.348	0.00078	14.00	7.38
Gl	5.123	2.472	0.00191	14.02	7.24
December 1993					
A2	0.352	0.392	0.00014	3.59	7.66
B2	0.703	0.406	0.00015	3.85	7.75
c2	0.151	0.164	0.00006	3.21	7.60
D2	0.204	0.635	0.00023	3.51	7.55
El	0.724	0.875	0.00021	3.76	7.63
Fl	0.388	0.587	0.00014	3.91	7.52
Gl	0.477	0.666	0.00016	4.03	7.42
February 1994					
A2	0.285	0.300	0.00011	6.18[a]	7.86
B2	0.310	0.202	0.00007	6.18	7.77
c2	0.239	0.275	0.00011	6.18	7.64
D2	0.163	0.509	0.00019	6.18	7.64
El	0.309	0.318	0.00008	6.18	7.65
F1	0.265	0.375	0.00009	6.18	7.55
G1	0.230	0.357	0.00009	6.18	7.47

[a]Temperatures taken only at inflow to the raceways.

Figure 35. Total unionized ammonia excretion (mg NH_3/day/pond) measured at the outflow of experimental raceways during die1 sampling in September 1993, December 1993, March 1993, and February 1994.



NH3reted (mg/pond/day)
3.5
3
2.5
2
1.5
1
0.5
0
A
B
C
D
E
F
G
Groups
September
December
March
February

represents only about l/200 of the amount of NH_4 excreted at the same time (Table 14).

Ammonia excretion rates (ug NH_3/hr/kg fish) were highest in September (Fig. 36). Rates for group B seemed unusually high in September and December when compared to other groups reared in raceways. Rates were comparable to those from Michigan ponds. No notable differences between groups occurred during the March and February samples.

Average NH_3 concentrations (ug/ml) experienced by fish in various experimental ponds is shown in Fig. 37. Highest average levels were found in group G in September. Values of unionized ammonia from samples in September are among some of the highest concentrations encountered during the measurements. Yet all of these estimates of unionized ammonia fall far short of the level of 0.015 ppm (=ug/ml) which first causes deleterious effects in trout (Piper et al., 1982). The decrease in pH resulting from increased metabolic activity at high temperatures and rearing densities serves to reduce the fraction of unionized ammonia during excretion. There seems to be little reason for concern about unionized ammonia levels reaching critical concentrations from rearing fish in water with low buffering capacity such as that found at Willamette Hatchery. In Eastern hatcheries, where hardness levels can reach 250 ppm or more, toxicity from unionized ammonia may be a more critical issue.

Toxic effects of unionized ammonia have been reported in several publications, but mostly for trout. Thurston and Russo (1983) reported an LC_{50} (96 hr) of 0.16 to 1.1 mg/L, which

Figure 36. Total unionized ammonia concentrations (ug NH_3/day/kg fish) measured at the outflow of experimental raceways during die1 sampling in September 1993, December 1993, March 1993, and February 1994.

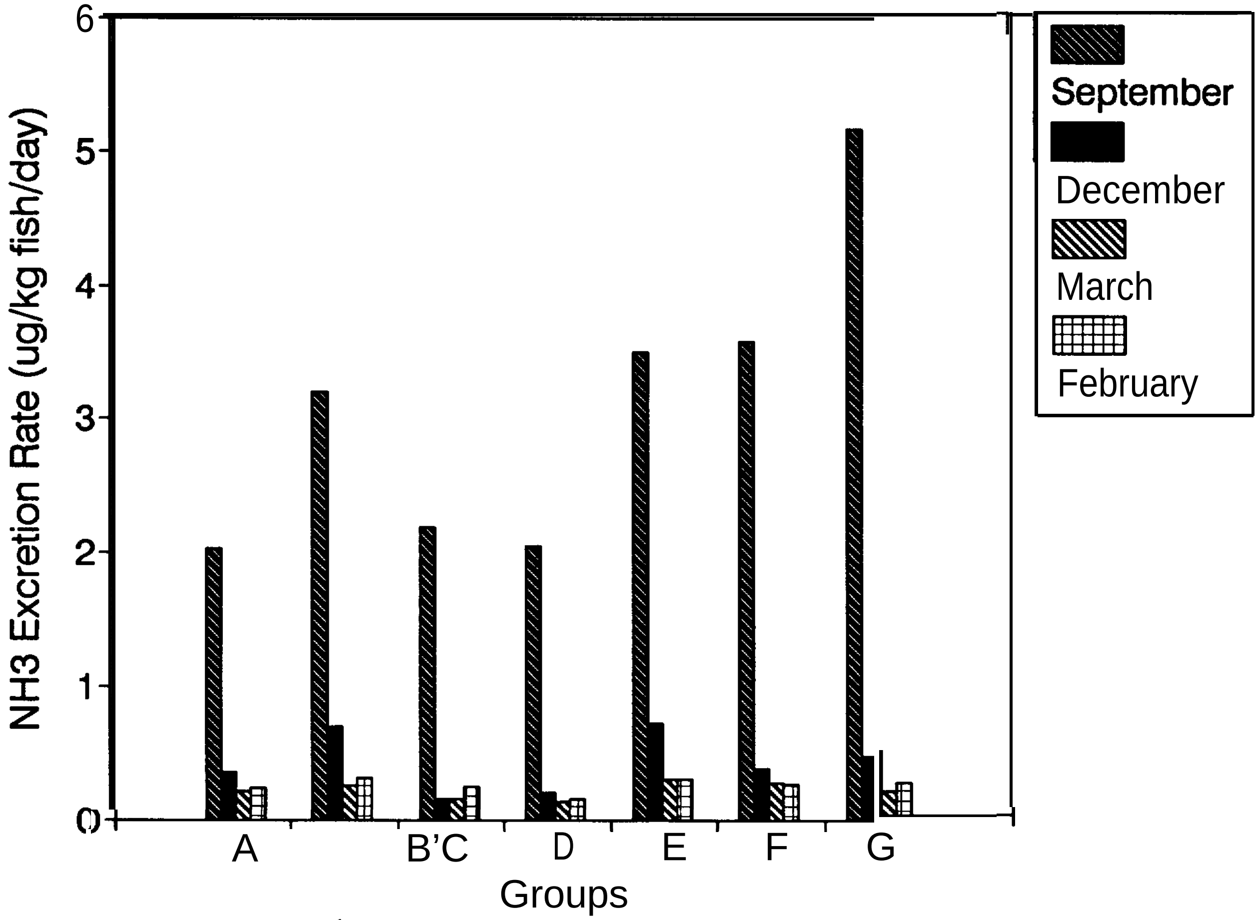
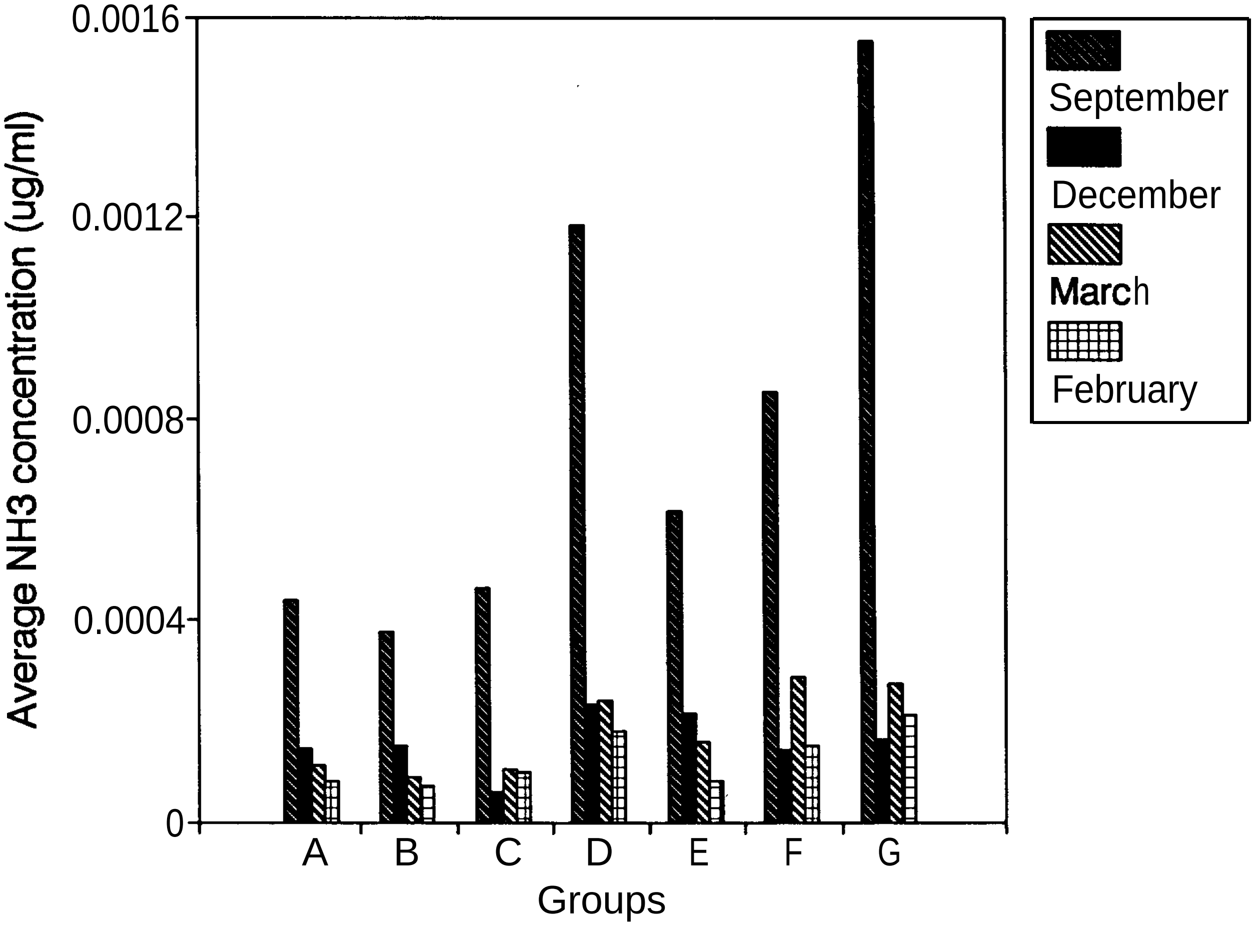

NH3 Excretion Rate (ug/kg fish/day)
0
1
2
3
4
5
6
A
B'C
D
E
F
G
Groups
September
December
March
February

Figure 37. Average unionized ammonia concentrations (ug/ml) at the outlets of experimental raceways during die1 sampling in September 1993, December 1993, March 1993, and February 1994.



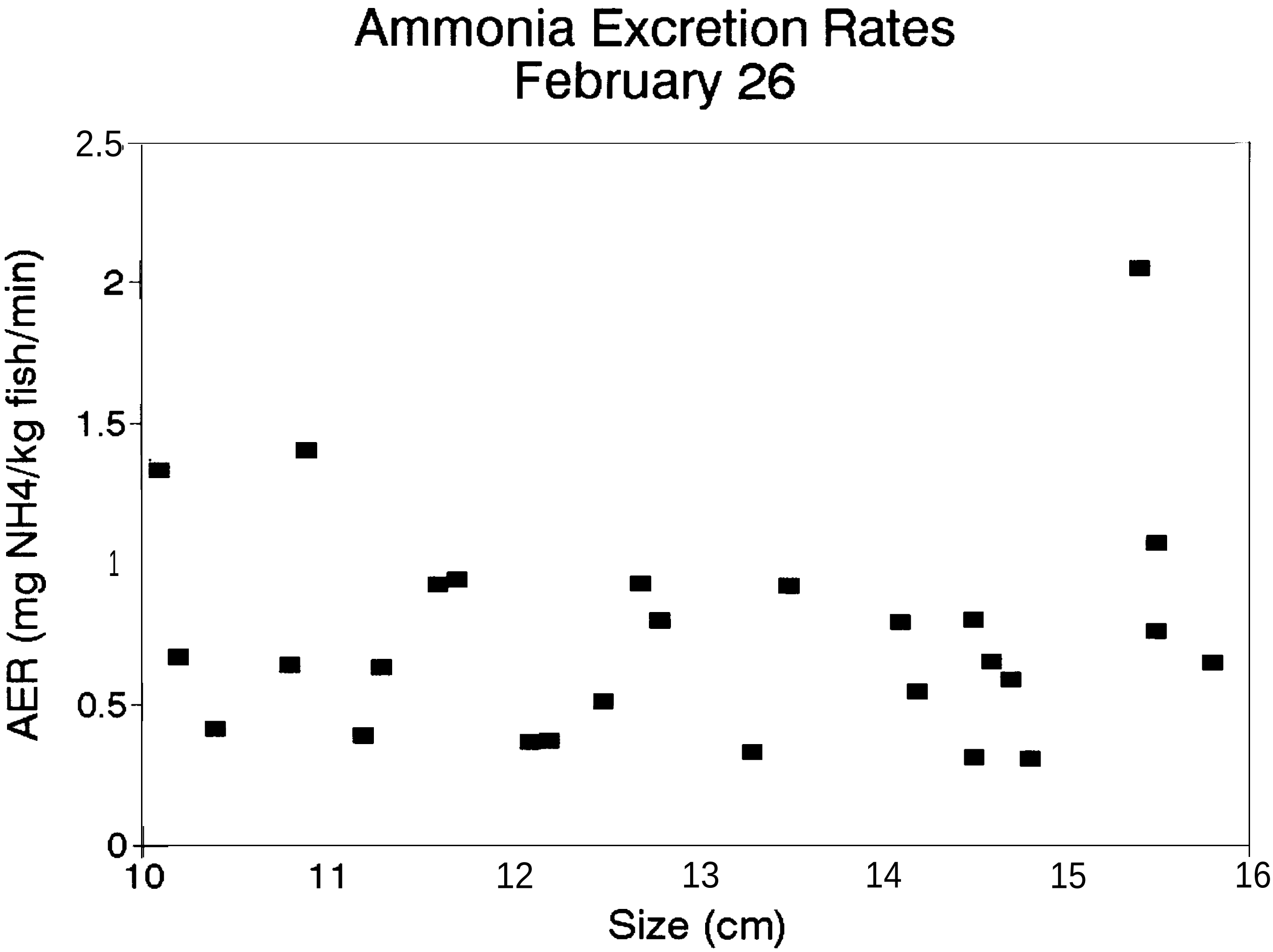
Average NH3 concentration (ug/ml)
0.0016
0.0012
0.0008
0.0004
0
A
B
C
D
E
F
G
Groups
September
December
March
February

corresponded in their experiments to a total ammonium concentration of 11-48 mg/L. Piper et al. (1982) indicated that deleterious effects were observed in trout only after concentrations of 0.015 mg/L had been reached. While the unionized ammonia levels in the present experiments did not reach concentrations correlated with deleterious effects in trout, they may have more subtle effects that influence the rates of survival. Chinook salmon are, in general, more subject to stresses than trout. In the Michigan pond series, which have some of the highest levels of ammonia encountered in these experiments, survival is low for the returns to date (see below). Ammonia concentrations (either ionized or unionized) may have contributed to this lack of vitality.

Effects of Size on AER in Coho Salmon

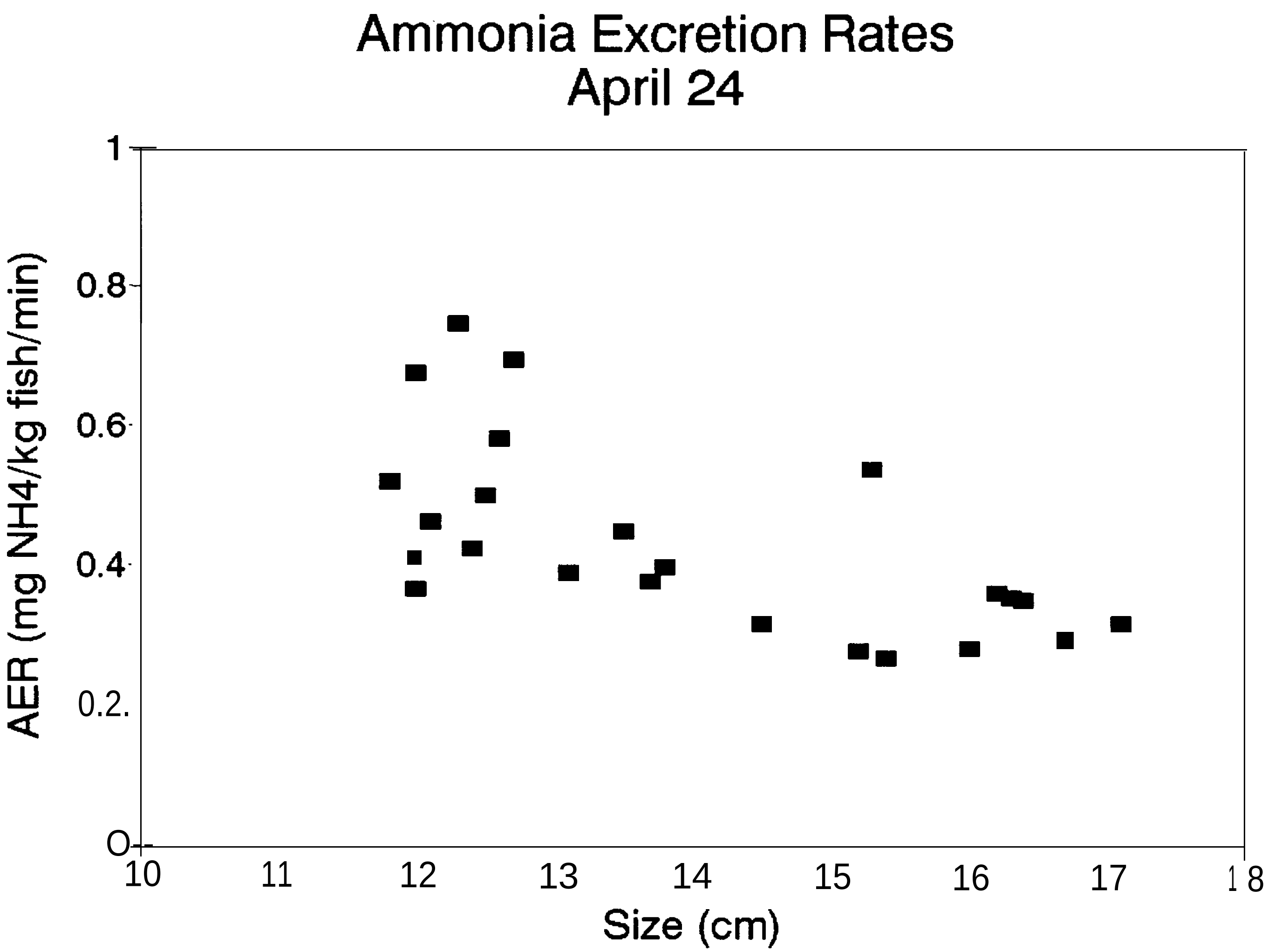
In a series of experiments at the Corvallis Fish Research Laboratory, we attempted to determine the effects on size on AER in coho salmon by isolating juveniles of differing sizes and measuring the AER of these fish thoughout the smolt cycle from February to June. Fish were held at constant temperature in plastic boxes of known volume for a period of 90 minutes. Samples were taken at 30 minutes intervals and analyzed for ammonium. Results suggested that size was not of major importance in determining AER (Fig. 38). As the fish entered the smolt cycle, however, as measured by an increase in (Na+K)-ATPase specific activity, a slight negative relationship between size in

Figure 38. Relationship between size (cm) and AER measured on 26 February 1995 in coho salmon under conditions of constant temperature at the Corvallis Fish Research Laboratory.


Ammonia Excretion Rates
February 26
AER (mg NH4/kg fish/min)
Size (cm)
0
0.5
1
1.5
2
2.5
10
11
12
13
14
15
16

cm and AER appeared (Fig. 39). These results suggest that the size of the juveniles at Willamette Hatchery probably had little influence on the changes in AER observed in the experimental ponds and that temperature was probably the most important factor in the variations.

Figure 39. Relationship between size (cm) and AER measured on 24 April 1995 in coho salmon under conditions of constant temperature at the Corvallis Fish Research Laboratory.



Ammonia Excretion Rates
April 24
AER (mg NH4/kg fish/min)
1
0.8
0.6
0.4
0.2
0
10
11
12
13
14
15
16
17
18
Size (cm)

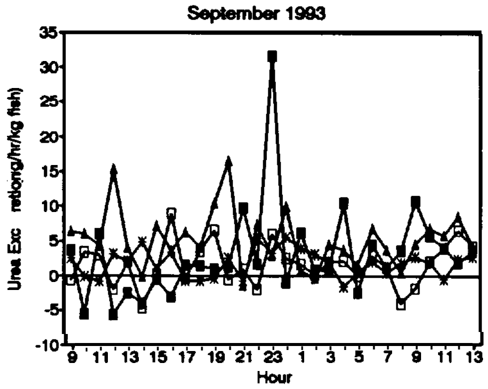
Analysis of Urea Excretion

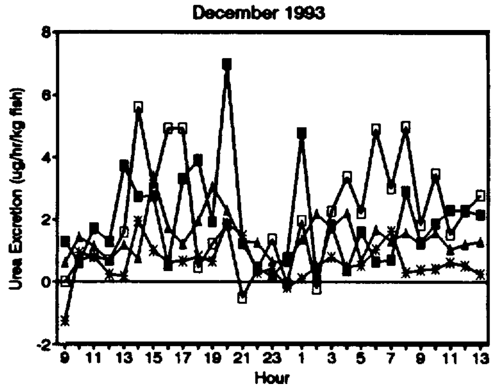
In addition to ammonium, gill membranes excrete a considerable amount of urea as a nitrogenous waste product. Urea is the second most abundant nitrogenous excretory product in fishes. The original sampling plan for water quality did not call for measurement of urea excretion and consequently no measurements of urea excretion were performed during the initial rearing years. During the final rearing year, however, urea concentrations were measured as part of the die1 measurement of ammonium excretion.

Measurements of urea excretion were performed in September and December 1993 and February 1994. Urea excretion rates (ug urea/hr/kg fish) (UERs) are shown for raceways (Fig. 40) and for Michigan ponds (Fig. 41). Several points can be seen from these curves. First, the urea excretion in September and December was only about l/3 the rate of ammonium excretion in both months. In February, however, the urea excretion exceeded ammonium excretion rates. Because the fish had been starved for several days before the measurements in February, ammonium excretion rates were reduced. Nitrogen excretion appeared to have been taken up by urea excretion rather than ammonium ions.

There was no evidence of a die1 cycle for urea excretion in these fish. Excretion rates seemed similar throughout the 24-hour period, although estimates of excretion rates at individual

Figure 40. Die1 changes in urea excretion rate (ug urea/hr/kg fish) in experimental raceways containing groups A2 (-■ -), B2 (-□-), C2 (-A-) and D2 (-*-) in September 1993, December 1993, and February 1994.


September 1993
Urea Exc retiong/hr/kg fish)
Hour


December 1993
Urea Excretion (ug/hr/kg fish)
Hour

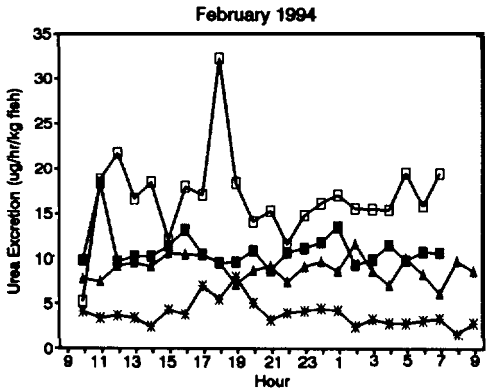
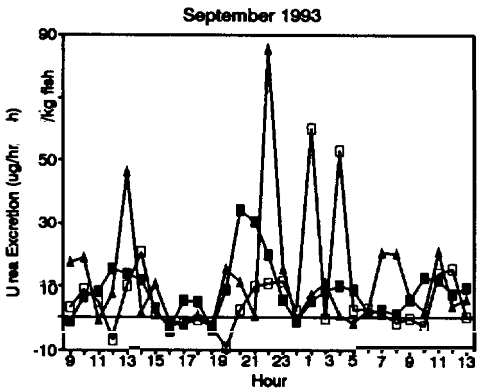
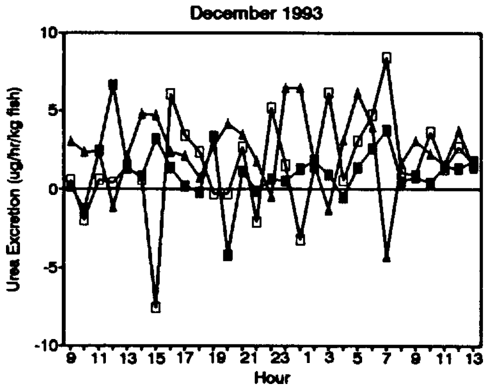
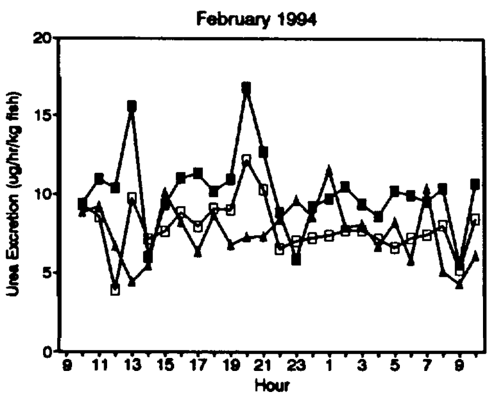

February 1994
Urea Excretion (ug/hr/kg fish)
Hour

Figure 41. Diel changes in urea excretion rate (ug urea/hr/kg fish) in experimental raceways containing groups El (-■-), Fl (-□-), and Gl (-▲-) in September 1993, December 1993, and February 1994.


September 1993
U rea Excretion (ug/hr/kg fish)
Hour


December 1993
Urea Excretion (ug/hr/kg fish)
Hour


February 1994
Urea Excretion (ug/hr/kg fish)
Hour

sampling times seemed variable. Because there was no die1 cycle, it was possible to look at average excretion rates for each raceway during the three sampling periods (Table 17; Fig. 42). Group D had the lowest UERs in each of the time periods. No other relationship was immediately evident from the graph, except that excretion rates overall were higher in February after starvation than in September, when the water was much warmer, ammonium ion excretion was high, and the fish were fed to repletion.

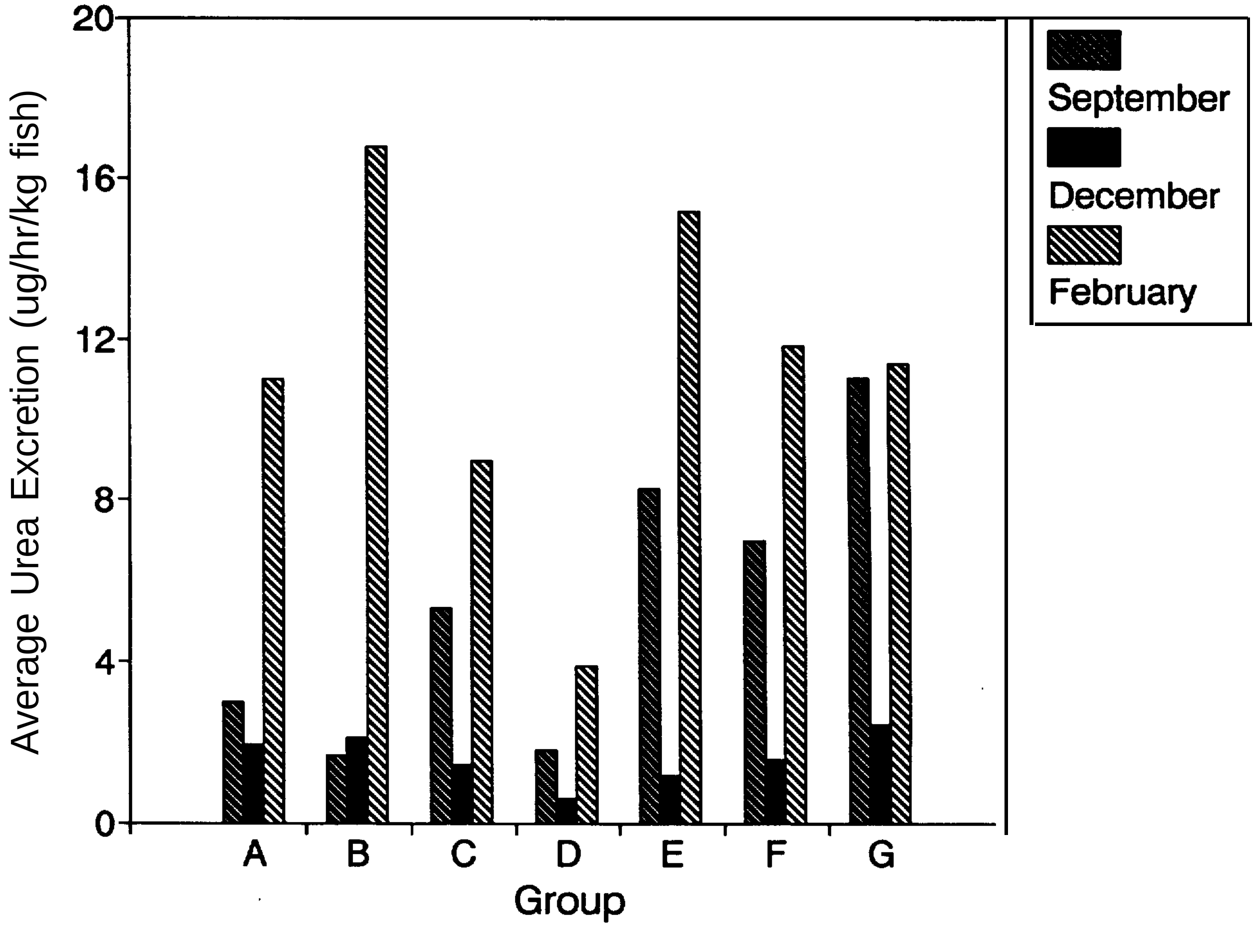
When total urea excreted per day (mg/day) was calculated for the experimental raceways (Fig. 43), similar amounts were observed in September and December for all raceways. In February, however, rates of urea excretion per day were over twice as high as those from the other time periods. At each time period, the most urea was excreted from group G, supporting the hypothesis that this group was stressed and had much higher metabolic rates.

Table 17 Total mg urea excreted per pond per day and average urea excretion rates (ug urea/kg fish) in experimental ponds measured hourly in September 1993, December 1993 and February 1994.

Date, group	Total NH_4[a] (mg/pond/day)	Ave. UER (ug/hr/kg fish)	Load[b] (kg/Lpm)
September 1993			
A2	41.92	3.00	4.86
B2	19.71	1.68	2.70
c2	70.42	5.32	3.18
D2	69.78	1.80	13.36
El	95.03	8.28	2.76
Fl	94.85	6.98	3.87
Gl	130.04	11.04	4.20
December 1993			
A2	53.63	1.94	4.86
B2	38.25	2.12	2.70
c2	59.41	1.45	3.18
D2	73.69	0.63	13.36
El	61.92	1.16	2.76
Fl	74.94	1.57	3.87
Gl	129.60	2.45	4.20
February 1994			
A2	283.79	11.01	4.86
B2	258.90	16.80	2.70
c2	248.11	8.96	3.18
D2	291.01	3.88	13.36
El	391.67	15.19	2.76
Fl	418.60	11.83	3.87
Gl	442.13	11.41	4.20

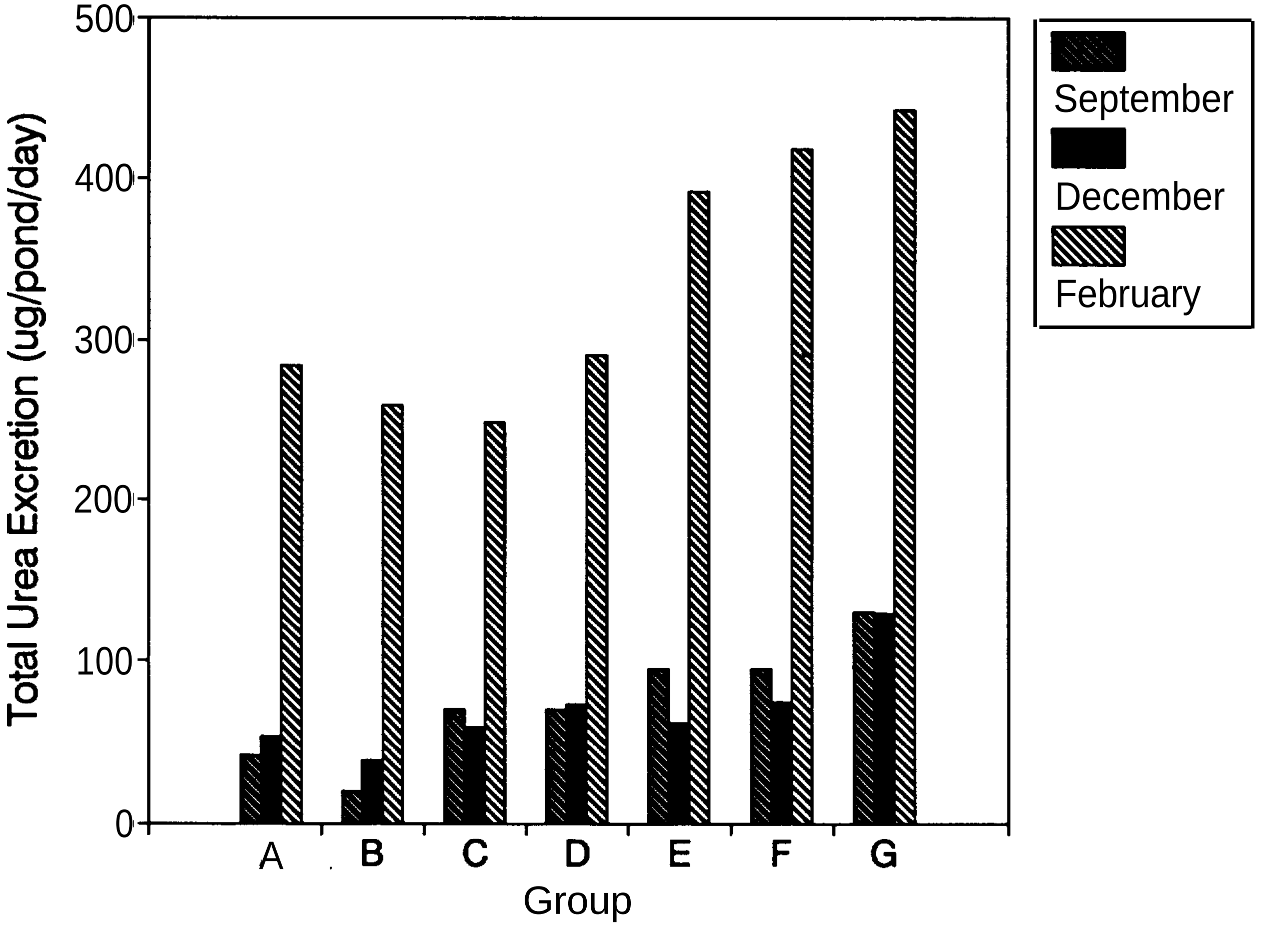
[a]Refers to the total output from the raceway for a 24-hour period.
[b]Load in each experimental raceway at the end of the experimental rearing.

Figure 42. Average urea excretion rate (ug urea/hr/kg fish) measured at the outflow of experimental raceways in September 1993, December 1993, and February 1994.



Average Urea Excretion (ug/hr/kg fish)
20
16
12
8
4
0
A
B
C
D
E
F
G
Group
September
December
February

Figure 43. Total urea excretion (mg urea/pond/day) measured at the outflow of experimental raceways in September 1993, December 1993, and February 1994.



Total Urea Excretion (ug/pond/day)
500
400
300
200
100
0
A
B
C
D
E
F
G
Group
September
December
February

Nitrogen Flow Through the Raceways

Nitrogen flow through the raceways can be determined by knowing the amount of nitrogen entering the system, the nitrogen accumulated in the fish as growth, and the nitrogen flowing out of the system as waste products. This can be represented by the formula:

$$N\ (\text{water}) + N\ (\text{feed}) = N\ (\text{fish growth}) + N\ (\text{effluent}) + N\ (\text{feces}) + N\ (\text{micro-organisms}) \quad (15)$$

In our analyses, we found little N as ammonium, nitrite or nitrate coming into the system through the water system. We did not attempt to measure N flow in the bacteria living in the raceways, but since the raceways were kept reasonably clean, we have made the assumption that the N incorporated into or excreted by micro-organisms was negligible. Thus, the equation becomes:

$$N\ (\text{feed}) = N\ (\text{fish growth}) + N\ (\text{feces}) + N\ (\text{effluent}) \quad (16)$$

Because we have information on most of these parameters, it is possible to determine the correctness of our assumptions.

Proximate analyses of Biomoist Feed and of juvenile chinook salmon were required for determination of the total nitrogen and water contents. Feed at Willamette Hatchery was not subjected to proximate analysis during the rearing of the juveniles, but a series of proximate analyses on BioMoist Feed at various Oregon hatcheries were performed in 1994. Averages of these results are presented in Table 18. Similarly, actual fish from experimental rearing years were not analyzed, but a series of chinook salmon from Willamette Hatchery were obtained in November 1994 and analyzed. These fish averaged 40 g in weight (11.4 fish per pound), which was similar to the target release size of 10 fish per pound.

Nitrogen balance was calculated in detail for the four periods of die1 sampling for ammonium because these represent the most accurate determinations of N excretion per day. Results are presented in Table 19. Negative values occurred when the nitrogen in soluble waste and in fish growth exceeded the nitrogen content of the feed introduced. Also, in February 1994, the fish were not fed for several days before release. The food is therefore 0 and all values for nitrogen in excretion and growth were negative.

Percent of the nitrogen in fish food that was incorporated into fish flesh was relatively constant during September when the fish were growing well (Fig. 44). During December, the percent incorporation was much less, with some negative figures in the Michigan ponds. Incorporation in March again approached the percent reached in September for fish reared in raceways, but not for those reared in Michigan ponds.

The percent of nitrogen in fish food that was excreted as soluble waste (NH4 and urea) was lowest in September and highest in December (Fig. 45). In December, percentages often exceeded 100% because the amount of food fed was variable and low. In March, the percent of N input excreted as soluble waste was

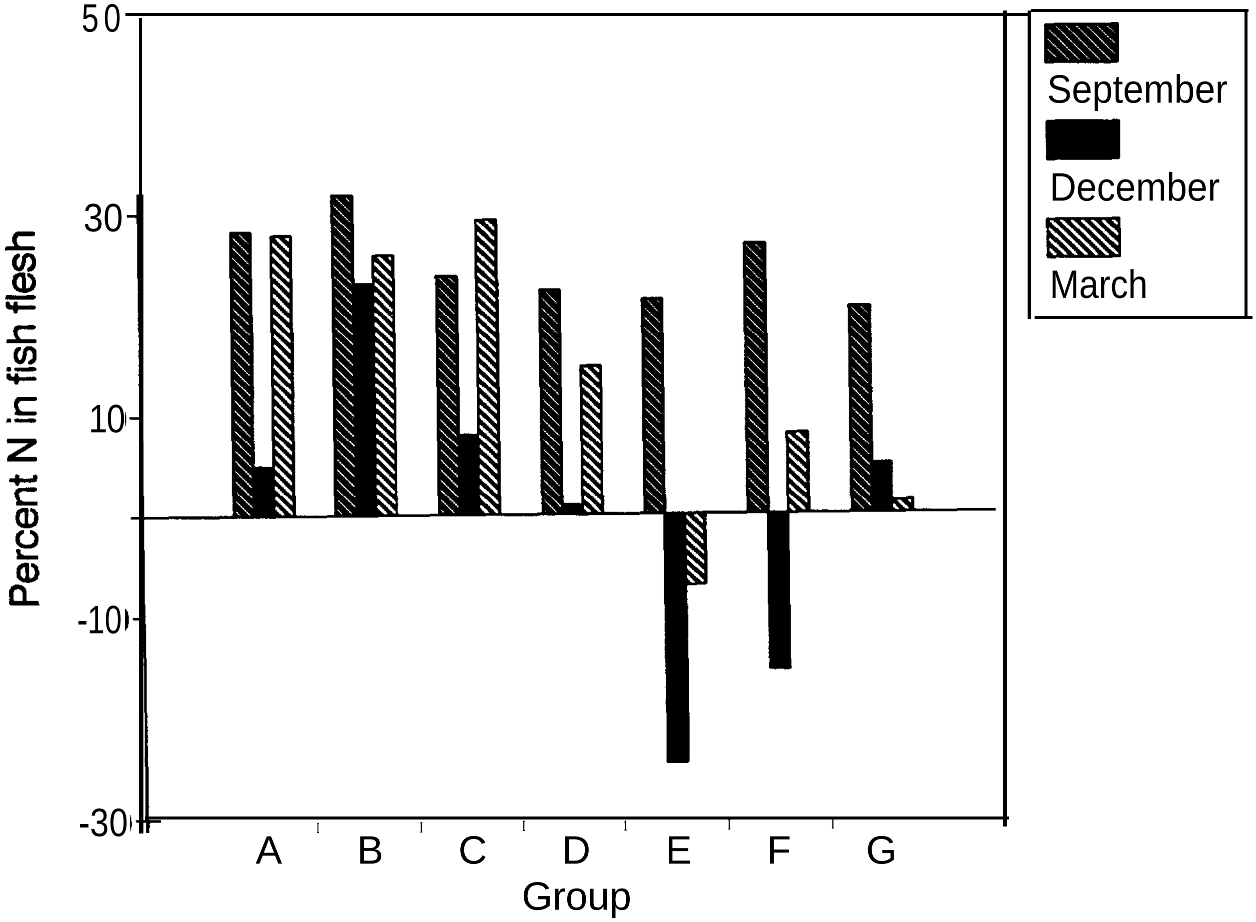
Table 18. Proximate analyses for chinook salmon (average size 40.6 ± 0.3) and BioMoist Feed. Chinook salmon were obtain in November 1994 for analysis. Feed samples represent averages of samples from various Oregon hatcheries in 1994.

	Percent Analyte			
Analyte	Chinook Salmon	N	BioMoist Feed	N
Water	74.85 ± 0.29	16	27.62 ± 0.46	13
Ash	1.95 ± 0.02	5	7.30 ± 0.43	13
Protein	12.83 ± 0.93	6	34.97 ± 1.37	9
Lipid	7.48 ± 0.60	6	13.97 ± 0.49	9
Total	97.11 ± 1.07	6	84.32 ± 1.56	9

Table 19. Nitrogen flow in grams through various experimental raceways during the four periods of measurement of die1 ammonium excretion.

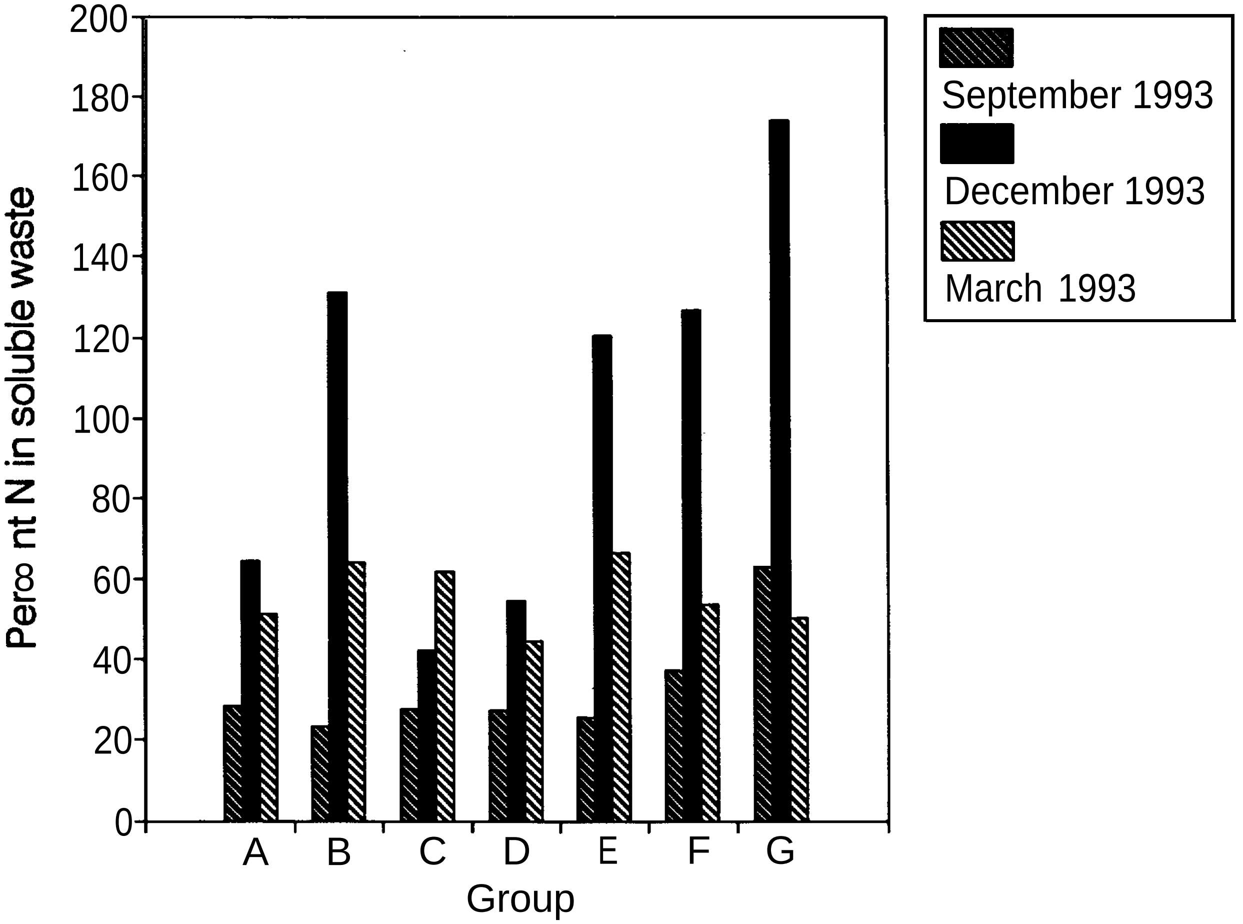
Date, group	N (food)	N (growth)	N (soluble waste)	Difference	Percent
March 3-4, 1993					
A	279.8	78.1	143.5	58.1	20.8
B	179.0	46.3	114.9	17.8	10.0
C	251.8	73.9	155.9	22.0	8.7
D	760.9	112.4	339.4	309.2	40.6
E	430.8	-30.5	286.2	175.1	40.7
F	637.9	51.0	340.6	246.3	38.6
G	788.9	10.0	395.3	383.7	48.6
September 7-8, 1993					
A	710.6	201.4	201.5	307.8	43.3
B	408.4	130.3	95.6	182.6	44.7
C	760.9	181.4	210.8	368.8	48.5
D	2489.9	555.0	681.8	1253.1	50.3
E	917.6	197.0	235.5	485.1	52.9
F	917.6	246.5	342.8	328.3	35.8
G	1068.7	220.8	671.8	176.1	16.5
December 16-17, 1993					
A	201.4	10.0	129.8	61.6	30.6
B	78.3	18.1	102.8	-42.6	-54.3
C	229.4	18.5	97.0	114.0	49.7
D	430.8	4.1	235.1	191.6	44.5
E	201.4	-49.7	243.0	8.1	4.0
F	179.0	-27.7	226.9	-20.2	-11.3
G	201.4	10.0	350.6	-159.2	-79.0
February 27-28, 1994					
A	0.0	-8.6	292.6	-284.0	
B	0.0	18.1	262.0	-280.1	
C	0.0	18.5	294.8	-313.3	--
D	0.0	4.1	376.8	-380.9	--
E	0.0	-49.7	313.7	-264.0	--
F	0.0	-27.7	356.4	-328.7	--
G	0.0	10.0	383.4	-393.4	

Figure 44. Percent of nitrogen in food that can be accounted for in fish growth in experimental ponds in September 1993, December 1993, and March 1993.



50
30
10
-10
-30
Percent N in fish flesh
A
B
C
D
E
F
G
Group
September
December
March

Figure 45. Percent of nitrogen in food that can be accounted for by soluble waste products (NH4 and urea) in experimental ponds in September 1993, December 1993, and March 1993. Urea excretion was not measured in March 1993.

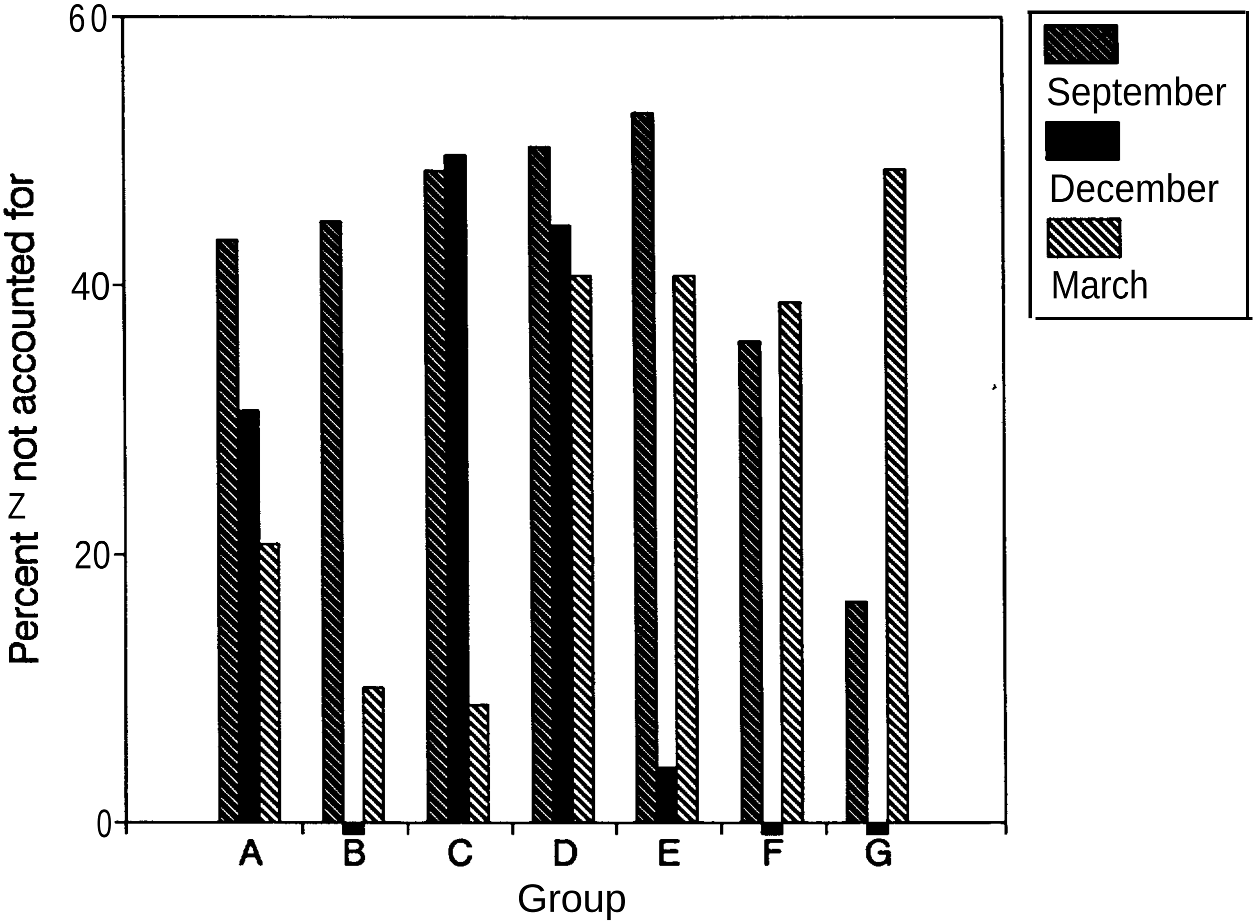


200
180
160
140
120
100
80
60
40
20
0
Perce nt N in soluble waste
A
B
C
D
E
F
G
Group
September 1993
December 1993
March 1993

fairly stable for all raceways at 50-60%.

A disturbing aspect is that, in many cases, almost half of the nitrogen introduced in the food was unaccounted for by nitrogen in growth or in soluble wastes (Fig. 46). Nearly half the N input in feed in September was unaccounted for. Similar percents were found for raceways in December, although Michigan ponds showed only a small percent. In March, the percent unaccounted for was reduced in raceways but eleveated in Michigan ponds. Either a huge amount of nitrogen was present in the feces, which seems unlikely from other accounts (Kaushik and Cowey 1991; Pillay 19921 a large amount of food was uneaten, which also seems unlikely from the food conversion analyses and the lack of appearance of uneaten food on the bottom of the raceway, or the unequal distributions of feed and excretion during the single day of measurement caused large discrepancies in nitrogen flow. The present study was not designed to account for nitrogen flow through the raceways, although many of the parameters necessary for these calculations were measured. A better study for nitrogen flow through the raceways might be to examine nitrogen flow through the system for a weekly period rather than a single day, so that differences in feeding rates and excretion rates that lead to large variations in values could be smoothed out.

Figure 46. Percent of nitrogen in food that could not be accounted for by fish growth or soluble waste in experimental ponds in September 1993, December 1993, and March 1993.



60
40
20
0
Percent N not accounted for
A
B
C
D
E
F
G
Group
September
December
March

Recoveries of Marked Adults

Information on survival of experimental groups was obtained from coded wire tags collected from adult returns to Dexter Rearing Facility, McKenzie Hatchery, Willamette Hatchery, and the ocean fisheries program and compiled by the Pacific Fisheries Management Council (PFMC) computer data base. Preliminary data on adult returns are shown in Tables 20 and 21. The highest percent returns were from fish that were reared at Willamette Hatchery until November and then transferred to the Dexter holding pond (Fig. 47). These fish were not part of the experimental design but were tagged for comparison with experimental fish. The number of fish reared each year varied: 147,859 for the 1989 brood, 382,000 for the 1990 brood, 382,024 for the 1991 brood and 308,727 for the 1992 brood

The second highest percent returns (Fig. 47) were from fish reared at half the normal rearing density (group B) followed by fish reared at normal density with oxygen (group C). Fish reared in Michigan ponds showed very poor recoveries.

It should be emphasized that these data are preliminary and any conclusions reached at this time will be subject to revision as more data becomes available and calculations become more refined.

Table 20. Capture of adult fish derived from experimental groups released from Willamette Hatchery, 1991-1994. Data is incomplete and represents only that available as of June 1995.

Group	Tag Code	Age at Capture 2	3	4	5	6	Total
1989 Brood							
Al	07-55-14	0	7	90	94	--	191
A2	07-55-06	0	3	73	64	--	140
Bl	07-55-17	0	1	111	51	--	163
B2	07-55-18	1	3	98	94	--	196
Cl	07-54-63	0	8	157	107	--	272
c2	07-55-03	0	1	160	85	--	246
Dl	07-55-07	0	2	85	41	--	128
D2	07-55-08	0	5	82	75	--	162
El	07-55-09	0	0	2	9	--	11
E2	07-55-10	0	1	15	5	--	21
Fl	07-55-11	0	0	9	0	--	9
F2	07-55-12	0	12	14	9	--	35
Gl	07-55-05	0	0	2	10	--	12
G2	07-55-13	0	0	4	7	--	11
Dexl	07-55-16	0	18	276	129	--	423
Dex2	07-55-15	0	14	228	109	--	351
1990 Brood							
Al	07-56-32	0	0	0	--	--	0
A2	07-56-31	1	1	25	--	--	27
Bl	07-40-44	0	0	3	--	--	3
B2	07-40-43	0	1	8	--	--	9
Cl	07-56-34	0	2	6	--	--	8
c2	07-56-33	0	0	1	--	--	1
Dl	07-56-36	0	0	3	--	--	3
D2	07-56-35	0	0	12	--	--	12
El	07-56-37	0	0	0	--	--	0
E2	07-56-38	0	0	1	--	--	1
Fl	07-56-39	0	0	0	--	--	0
F2	07-56-40	0	0	5	--	--	5
Gl	07-56-41	0	0	0	--	--	0
G2	07-56-42	0	5	6	--	--	11
Dexl	07-56-43	0	9	16	--	--	25
Dex2	07-56-44	7	6	24	--	--	37

Table 20 (cont.)

Group	Tag Code	Age at Capture 2	3	4	5	6	Total
1991 Brood							
A1	07-59-21	0	4	--	--	--	4
A2	07-59-22	0	1	--	--	--	1
B1	07-59-35	0	0	--	--	--	0
B2	07-59-36	0	1	--	--	--	1
C1	07-59-23	0	2	--	--	--	2
C2	07-59-24	0	7	--	--	--	7
D1	07-59-25	0	0	--	--	--	0
D2	07-59-26	0	0	--	--	--	0
E1	07-59-27	0	2	--	--	--	2
E2	07-59-28	0	0	--	--	--	0
F1	07-59-29	0	2	--	--	--	2
F2	07-59-30	0	0	--	--	--	0
G1	07-59-31	0	2	--	--	--	2
G2	07-59-32	0	0	--	--	--	0
Dex1	07-59-33	0	11	--	--	--	11
Dex2	07-59-34	0	4	--	--	--	4
1992 Brood							
A1	07-63-23	1	--	--	--	--	1
A2	07-63-22	1	--	--	--	--	1
B1	07-63-37	1	--	--	--	--	1
B2	07-63-36	2	--	--	--	--	2
C1	07-63-24	4	--	--			4
C2	07-63-25	0	--	--	--	--	0
D1	07-63-26	0	--	--	--	--	0
D2	07-63-27	1	--	--	--	--	1
E1	07-63-28	1	--	--	--	--	1
E2	07-01-28	0	--	--	--	--	0
F1	07-01-29	0	--	--	--	--	0
F2	07-01-30	1	--	--	--	--	1
G1	07-01-31	0	--	--	--	--	0
G2	07-01-32	0	--	--	--	--	0
Dex1	07-01-33	17	--	--	--	--	17
Dex2	07-01-34	15	--	--	--	--	15

Table 21. Percent recovery of adult fish derived from experimental groups released from Willamette Hatchery, 1991-1994. Data is incomplete and represents only that available as of June 1995.

Group	Tag Code	Number Released[a]	Number Recovered	Percent Recovery
1989 Brood				
A1	07-55-14	32,494	191	0.588
A2	07-55-06	27,950	140	0.501
B1	07-55-17	20,684	163	0.788
B2	07-55-18	20,031	196	0.978
C1	07-54-63	31,531	272	0.863
C2	07-55-03	32,078	246	0.767
D1	07-55-07	33,317	128	0.384
D2	07-55-08	28,975	162	0.559
E1	07-55-09	26,246	11	0.042
E2	07-55-10	29,440	21	0.071
F1	07-55-11	28,087	9	0.032
F2	07-55-12	30,366	35	0.115
G1	07-55-05	27,404	12	0.044
G2	07-55-13	26,596	11	0.041
Dex1	07-55-16	33,277	423	1.271
Dex2	07-55-15	32,993	351	1.064
1990 Brood				
A1	07-56-32	32,678	0	0.000
A2	07-56-31	32,121	27	0.084
B1	07-40-44	19,345	3	0.016
B2	07-40-43	20,091	9	0.045
C1	07-56-34	31,198	8	0.026
C2	07-56-33	31,527	1	0.003
D1	07-56-36	31,653	3	0.009
D2	07-56-35	32,886	12	0.036
E1	07-56-37	32,108	0	0.000
E2	07-56-38	29,778	1	0.003
F1	07-56-39	28,853	0	0.000
F2	07-56-40	30,804	5	0.016
G1	07-56-41	32,747	0	0.000
G2	07-56-42	32,103	11	0.034
Dex1	07-56-43	33,082	25	0.076
Dex2	07-56-44	33,045	37	0.112

[a]Refers to the number of tagged fish released. This is determined by multiplying the number of total fish released (from liberation truck displacements) times the proportion of tagged fish to total fish at the time of tagging.

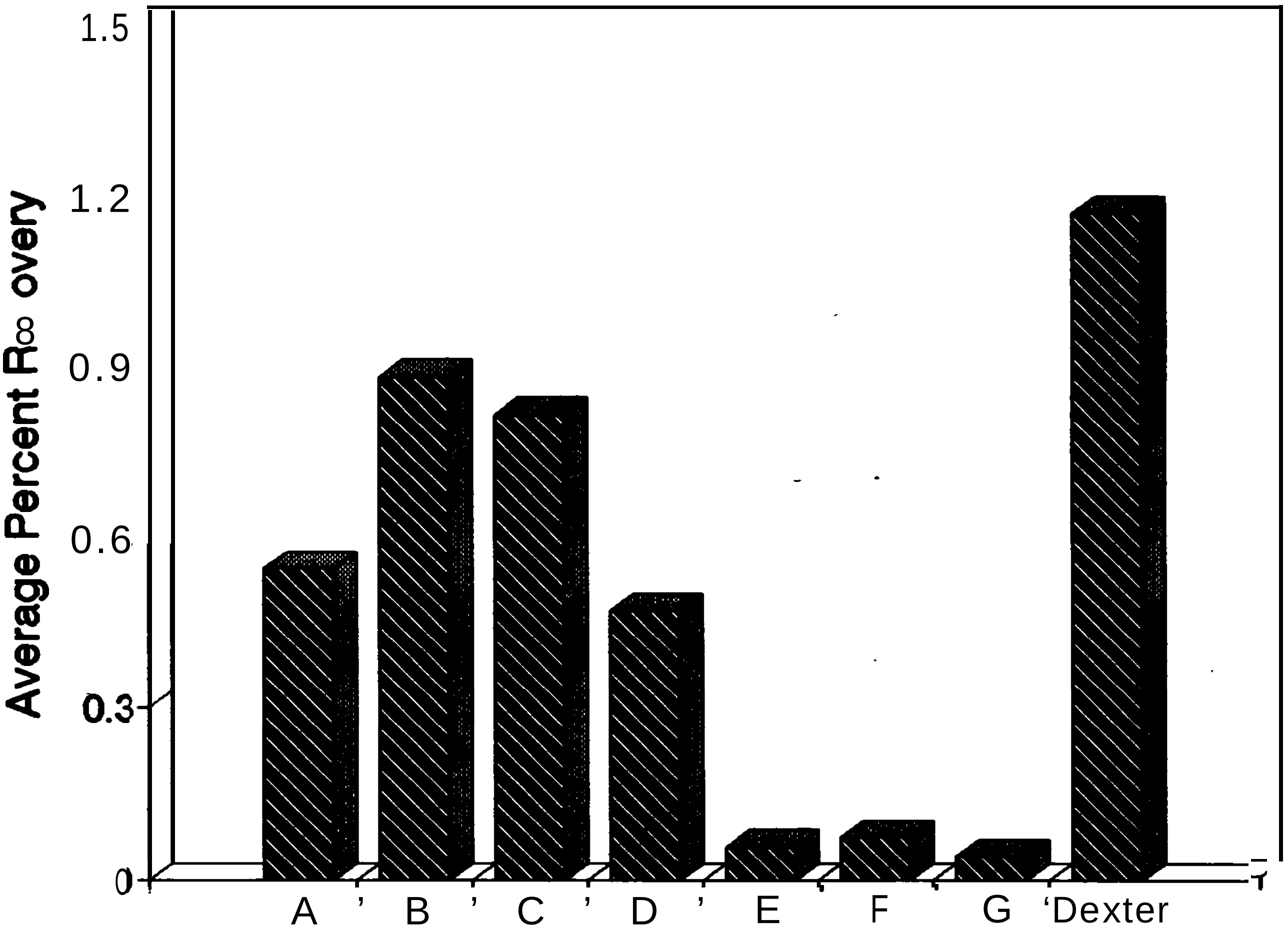
Table 21. (cont.)

Group	Tag Code	Number Released[a]	Number Recovered	Percent Recovery
1991 Brood				
A1	07-59-21	30,298	0	0.000
A2	07-59-22	29,253	1	0.003
B1	07-59-35	19,792	0	0.000
B2	07-59-36	19,968	1	0.005
C1	07-59-23	31,119	2	0.006
C2	07-59-24	29,993	7	0.023
D1	07-59-25	27,120	0	0.000
D2	07-59-26	27,832	0	0.000
E1	07-59-27	22,807	2	0.009
E2	07-59-28	23,691	0	0.000
F1	07-59-29	27,340	2	0.007
F2	07-59-30	25,649	0	0.000
G1	07-59-31	28,135	2	0.007
G2	07-59-32	26,071	0	0.000
Dex1	07-59-33	31,647	11	0.035
Dex2	07-59-34	31,505	4	0.013
1992 Brood				
A1	07-63-23	31,518	1	0.003
A2	07-63-22	29,866	1	0.003
B1	07-63-37	17,550	1	0.006
B2	07-63-36	17,550	2	0.011
C1	07-63-24	29,691	4	0.013
C2	07-63-25	27,145	0	0.000
D1	07-63-26	31,799	0	0.000
D2	07-63-27	29,694	1	0.003
E1	07-63-28	23,923	1	0.004
E2	07-01-28	22,640	0	0.000
F1	07-01-29	27,357	0	0.000
F2	07-01-30	26,619	1	0.004
G1	07-01-31	28,615	0	0.000
G2	07-01-32	27,493	0	0.000
Dex1	07-01-33	32,000	17	0.053
Dex2	07-01-34	31,892	15	0.047

[a]Refers to the number of tagged fish released. This is determined by multiplying the number of total fish released (from liberation truck displacements) times the proportion of tagged fish to total fish at the time of tagging.

Figure 47. Percent recoveries of 1989-brood chinook salmon reared in experimental raceways at Willamette Hatchery. Recoveries are still incomplete and the data should be considered as preliminary. Values are averages of recoveries from the two replicate raceways.

1989 Brood Chinook Salmon



SUMMARY

1) Ammonium excretion rates (AERs) were calculated by determination of fish size from fitted growth curves, and ammonium concentrations and flow rates of the effluent water.

2) Much of the yearly variation in AER could be described by the relatively simple formula:

$$AER = e^{-A/T+B}$$

where AER is expressed as ug NH_4 excreted/hr/kg fish, T is the absolute temperature (^{o}K), and A and B are constants presented in Table 6 for the four brood years.

3) The use of this simple formula permitted estimates of fish populations when water temperature, fish/kg, ammonium concentrations, and water flow were known. Correspondence to other measurements of fish population were not particularly good, but refinements of the method may prove useful for non-stressful estimates of populations.

4) Measurements of both AER and urea excretion rates (UER) suggested that fish in the Michigan pond series were metabolizing much more rapidly than fish of corresponding densities in the raceway series.

5) Diel cycles of ammonium excretion occur with the maximum excretion levels closely following changes in water temperature. Excretion at the same temperature, however, is much greater during the active daylight hours than at night.

6) Urea excretion rates did not undergo diel changes and seemed to be highly variable. In February 1994, after fish had been starved for three days, urea excretion rates were elevated. Further study is required to determine if there is a relationship between ammonium and urea excretion in chinook salmon that is determined by food intake or whether the increased urea excretion is a function of the onset of smolting in the spring.

7) Unionized ammonia concentrations did not at any time reach levels currently considered deleterious to fish health. As fish rearing density increased, the pH of effluent water decreased, which reduced the dissociation of ammonium ions into unionized ammonia. We feel that in unbuffered surface water, unionized ammonia will probably never reach the deleterious levels indicated in the literature, regardless of rearing density. However, preliminary returns of marked fish in the Michigan pond series showed reduced survival, suggesting that, in addition to other factors considered in later reports, levels of NH_3 or NH_4 below that necessary for visible lesions may cause rearing stresses that result in impaired ability to survive to adulthood.

8) Preliminary analysis of recoveries of adults from experimental rearing groups indicated that survival was inversely related to rearing density, oxygen could help relieve the effects of increased rearing density, and fish reared in Michigan ponds were recovered in much lower numbers than fish reared at similar densities in raceways.

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APPENDIX A

Growth Parameters for Chinook Salmon reared in Experimental Raceways at Willamette Hatchery, 1990-1994.

Year, Group	Number of Fish	Fish/kg	G/Fish	Total kg
1990-1991				
Group A2				
August	39,572	147.1	6.8	269.1
September	39,511	78.7	12.7	501.8
October	39,487	46.1	21.7	856.9
November	39,441	34.2	29.2	1151.7
December	39,393	35.1	28.5	1122.7
January	39,362	37.3	26.8	1054.9
February	39,331	36.0	27.8	1093.4
March*	33,300	26.0	38.5	1280.8
Group B2				
August	20,012	166.7	6.0	120.1
September	19,968	86.2	11.6	231.6
October	19,932	39.2	25.5	508.3
November	19,903	37.6	26.6	529.4
December	19,872	36.4	27.5	546.5
January	19,842	31.9	31.3	621.1
February	19,814	31.1	32.2	638.0
March*	18,264	24.2	41.3	757.7
Group C2				
August	38,976	149.3	6.7	261.1
September	38,904	85.5	11.7	455.2
October	38,853	45.2	22.1	858.7
November	38,826	37.7	26.5	1028.9
December	38,785	37.5	26.7	1035.6
January	38,738	33.3	30.0	1162.1
February	38,706	32.5	30.8	1192.1
March*	38,960	23.4	42.7	1664.9

*Estimated from displacement measurements in liberation trucks.

Appendix A (cont).

Year, Group	Number of Fish	Fish/kg	G/Fish	Total kg
1990-1991				
Group D2				
August	116,964	163.9	6.1	713.5
September	116,968	91.7	10.9	1272.8
October	116,932	51.8	19.3	2250.9
November	116,903	37.0	27.0	3146.3
December	116,872	38.6	25.9	3015.0
January	116,842	38.2	26.2	3048.3
February	116,814	35.1	28.5	3314.2
March*	100,792	26.7	37.5	3774.5
Group E1				
August	59,621	158.7	6.3	375.6
September	59,551	100.0	10.0	595.5
October	59,489	61.3	16.3	969.7
November	59,432	48.3	20.7	1230.2
December	59,401	44.1	22.7	1348.4
January	59,372	51.8	19.3	1145.9
February	59,346	49.5	20.2	1198.8
March*	47,260	34.6	28.9	1365.9
Group F1				
August	59,025	149.3	6.7	395.5
September	58,961	85.5	11.7	689.8
October	58,932	51.8	19.3	1137.4
November	58,877	40.0	25.0	1471.9
December	58,831	38.0	26.3	1547.3
January	58,791	35.0	28.6	1681.4
February	58,747	40.5	24.7	1451.1
March*	50,480	30.2	33.1	1671.5
Group G1				
August	59,740	169.5	5.9	352.5
September	59,696	102.0	9.8	585.0
October	59,667	58.5	17.1	1020.3
November	59,608	45.7	21.9	1305.4
December	59,578	45.9	21.8	1298.8
January	59,543	41.8	23.9	1423.1
February	59,508	35.3	28.3	1684.1
March*	49,341	32.7	30.6	1508.9

*Estimated from displacement measurements in liberation trucks.

Appendix A (cont).

Year, Group	Number of Fish	Fish/kg	G/Fish	Total kg
1991-1992				
Group A1				
August	39,304	64.7	15.5	607.7
September	39,293	38.3	26.1	1026.5
October	39,272	27.5	36.4	1428.1
November	39,265	25.7	38.9	1525.4
December	39,102	25.7	38.9	1519.1
January	39,086	24.9	40.2	1572.2
February	39,046	22.9	43.7	1704.9
March*	38,881	22.9	43.7	1697.9
Group A2				
August	39,709	64.2	15.6	618.1
September	39,705	40.3	24.8	916.2
October	39,694	30.1	33.2	1317.0
November	39,694	28.8	34.7	1377.3
December	39,663	28.8	34.7	1376.2
January	39,649	25.3	39.5	1567.2
February	39,597	22.5	44.4	1762.8
March*	38,511	23.3	43.0	1654.3
Group B1				
August	20,505	58.7	17.0	349.1
September	20,498	38.9	25.7	526.4
October	20,485	28.6	35.0	716.3
November	20,481	24.2	41.3	846.3
December	20,464	23.5	42.6	869.3
January	20,456	23.5	42.6	869.0
February	20,416	20.1	49.8	1017.5
March*	19,345	19.9	50.3	972.6

*Estimated from displacement measurements in liberation trucks.

Appendix A (cont).

Year, Group	Number of Fish	Fish/kg	G/Fish	Total kg
1991-1992				
Group B2				
August	20,029	58.7	17.0	341.1
September	20,024	41.1	24.3	486.7
October	20,009	28.2	35.5	710.5
November	20,000	26.8	37.3	745.2
December	19,978	29.5	33.9	677.6
January	19,971	26.2	38.2	762.8
February	19,928	23.0	43.5	866.8
March*	21,546	22.6	44.3	954.6
Group Cl				
August	39,653	69.1	14.5	574.0
September	39,638	45.8	21.9	866.4
October	39,621	30.1	33.2	1314.8
November	39,615	26.8	37.3	1476.2
December	39,546	26.4	37.9	1498.2
January	39,529	26.0	38.5	1522.9
February	39,474	22.2	45.0	1774.9
March*	37,420	22.2	45.0	1684.1
Group C2				
August	39,484	83.4	12.0	473.7
September	39,480	46.4	21.5	850.7
October	39,452	33.0	30.3	1195.7
November	39,452	29.9	33.4	1318.8
December	39,432	30.8	32.5	1280.6
January	39,411	27.7	36.1	1422.2
February	39,326	24.9	ho.2	1582.4
March*	37,474	24.7	40.5	1518.4
Group D1				
August	118,553	77.9	12.8	1522.7
September	118,503	49.5	20.2	2394.2
October	118,460	34.5	29.0	3429.9
November	118,452	31.9	31.4	3714.0
December	118,367	30.8	32.5	3843.9
January	118,325	31.5	31.8	3762.0
February	118,151	27.0	37.0	4370.9
March*	113,436	27.0	37.0	4195.1

*Estimated from displacement measurements in liberation trucks.

Appendix A (cont).

Year, Group	Number of Fish	Fish/kg	G/Fish	Total kg
1991-1992				
Group D1				
August	118,343	84.1	11.9	1407.6
September	118,313	50.2	19.9	2358.5
October	118,268	39.6	25.3	2986.8
November	118,268	35.4	28.2	3339.3
December	118,178	31.7	31.6	3730.2
January	118,120	32.8	30.5	3603.2
February	117,897	29.2	34.3	4040.9
March*	120,854	29.3	34.2	4127.5
Group E1				
August	59,516	78.1	12.8	761.8
September	59,508	46.2	21.6	1287.8
October	59,504	38.9	25.7	1528.1
November	59,504	29.3	34.2	2033.9
December	59,502	34.8	28.8	1711.9
January	59,493	32.3	30.9	1839.5
February	59,442	35.6	28.1	1668.6
March*	58,016	34.5	29.0	1681.6
Group E2				
August	59,359	72.2	13.9	822.5
September	59,356	53.9	18.5	1100.9
October	59,350	45.1	22.2	1315.6
November	59,350	38.1	26.3	1558.9
December	59,345	39.2	25.5	1514.9
January	59,338	33.7	29.7	1762.2
February	59,289	34.6	28.9	1713.9
March*	53,524	35.1	28.5	1527.1
Group F1				
August	59,332	74.8	13.4	793.4
September	59,327	45.5	22.0	1302.9
October	59,334	36.5	27.4	1624.4
November	59,334	33.0	30.3	1797.6
December	59,319	30.6	32.7	1939.8
January	59,313	29.5	33.9	2012.0
February	59,277	29.9	33.4	1980.0
March*	51,952	29.9	33.4	1736.4

*Estimated from displacement measurements in liberation trucks.

Appendix A (cont).

Year, Group	Number of Fish	Fish/kg	G/Fish	Total kg
1991-1992				
Group F2				
August	59,357	78.3	12.8	758.1
September	59,353	46.2	21.7	1285.1
October	59,348	40.7	24.6	1458.9
November	59,348	32.5	30.7	1823.3
December	59,346	30.1	33.2	1969.8
January	59,341	29.5	33.9	2013.6
February	59,293	28.9	34.6	2049.9
March*	55,455	28.8	34.7	1922.9
Group G1				
August	59,593	78.1	12.8	763.1
September	59,588	46.2	21.6	1289.8
October	59,577	36.1	27.7	1651.2
November	59,577	32.8	30.5	1817.5
December	59,571	32.6	30.7	1829.8
January	59,561	32.3	30.9	1842.0
February	59,316	29.2	34.3	2033.7
March*	58,804	29.0	34.5	2029.8
Group G2				
August	59,621	77.2	13.0	772.1
September	59,615	49.3	20.3	1209.6
October	59,605	36.1	27.7	1651.7
November	59,605	28.6	35.0	2083.8
December	59,593	27.5	36.4	2166.8
January	59,538	28.8	34.7	2065.4
February	59,274	28.8	34.8	2061.0
March*	57,627	28.5	35.1	2022.7
1992-1993				
Group A1				
August	39,417	50.0	20.0	789.2
September	39,401	30.3	33.0	1301.1
October	39,390	26.2	38.2	1505.5
November	39,324	23.7	42.1	1656.4
December	39,304	22.4	44.6	1753.8
January	39,286	22.6	44.2	1737.3
February	39,259	20.6	48.6	1908.8
March*	37,014	20.4	49.0	1814.4

*Estimated from displacement measurements in liberation trucks.

Appendix A (cont).

Year, Group	Number of Fish	Fish/kg	G/Fish	Total kg
1992-1993				
Group A2				
August	39,519	48.3	20.7	818.4
September	39,499	38.8	25.8	1019.4
October	39,471	36.9	27.1	1070.0
November	39,446	40.6	24.6	970.7
December	39,414	32.9	30.4	1198.6
January	39,385	27.5	36.4	1434.0
February	39,352	27.9	35.8	1409.2
March*	36,480	20.9	47.8	1745.5
Group B1				
August	19,849	43.9	22.8	452.5
September	19,839	32.6	30.7	609.0
October	19,837	24.9	40.2	797.4
November	19,833	22.7	44.1	874.6
December	19,811	23.8	42.1	834.0
January	19,804	22.9	43.7	865.4
February	19,794	20.1	49.7	983.7
March*	19,792	19.9	50.3	994.6
Group B2				
August	19,868	44.3	22.6	448.8
September	19,839	33.5	29.9	592.9
October	19,807	29.8	33.6	665.3
November	19,782	27.1	36.9	729.7
December	19,754	24.5	40.9	807.7
January	19,734	21.6	46.3	913.4
February	19,711	21.6	46.3	912.4
March*	19,615	21.2	47.3	927.6
Group C1				
August	39,428	51.9	19.3	759.7
September	39,416	31.1	32.2	1267.3
October	39,398	27.7	36.1	1420.4
November	39,386	23.3	42.9	1687.8
December	39,367	24.0	41.7	1639.7
January	39,355	21.3	46.9	1843.9
February	39,343	20.1	49.8	1957.4
March*	38,211	18.5	54.1	2065.5

*Estimated from displacement measurements in liberation trucks.

Appendix A (cont).

Year, Group	Number of Fish	Fish/kg	g/Fish	Total kg
1992-1993				
Group C2				
August	39,966	44.6	22.4	896.7
September	39,940	32.2	31.0	1239.6
October	39,894	26.2	38.2	1525.4
November	39,860	24.2	41.3	1647.6
December	39,830	24.2	41.3	1646.4
January	39,804	22.9	43.7	1740.8
February	39,775	19.7	50.8	2022.0
March*	38,023	20.6	48.5	1845.8
Group D1				
August	118,501	50.4	19.9	2352.1
September	118,439	32.7	30.6	3618.1
October	118,394	27.5	36.4	4303.4
November	118,364	23.8	42.1	4977.0
December	118,331	24.9	40.2	4750.8
January	118,290	21.6	46.4	5482.6
February	118,219	23.7	42.2	4982.8
March*	101,943	20.7	48.3	4924.8
Group D2				
August	119,590	51.7	19.4	2314.0
September	119,507	34.9	28.7	3423.8
October	119,432	27.7	36.1	4305.5
November	119,369	26.0	38.5	4589.7
December	119,288	24.7	40.6	4837.1
January	119,180	24.9	40.2	4785.0
February	119,128	23.7	42.3	5033.1
March*	105,792	21.2	47.2	4993.4
Group E1				
August	59,214	47.5	21.0	1245.6
September	59,189	40.3	24.8	1470.0
October	59,152	25.1	39.8	2356.4
November	59,139	27.1	36.9	2184.3
December	59,077	28.4	35.2	2081.6
January	59,013	26.4	37.8	2232.8
February	58,969	28.0	35.7	2107.3
March*	42,883	26.8	37.3	1600.1

*Estimated from displacement measurements in liberation trucks.

Appendix A (cont.)

Year, Group	Number of Fish	Fish/kg	g/Fish	Total kg
1992-1993				
Group E2				
August	59,091	56.0	17.9	1056.0
September	59,066	42.3	23.7	1398.1
October	59,048	30.1	33.3	1964.5
November	59,017	28.9	34.6	2040.2
December	58,951	29.8	33.6	1979.0
January	58,700	32.0	31.3	1835.6
February	58,131	29.2	34.3	1992.2
March*	44,016	28.7	34.8	1533.7
Group F1				
August	58,432	52.1	19.2	1121.2
September	58,389	37.9	26.4	1540.8
October	58,352	31.5	31.8	1854.9
November	58,304	26.2	38.2	2226.5
December	58,265	26.0	38.5	2242.5
January	58,169	25.8	38.8	2256.3
February	58,114	26.3	38.1	2213.4
March*	50,580	26.3	38.0	1923.2
Group F2				
August	58,284	54.0	18.5	1079.8
September	58,225	36.3	27.5	1602.7
October	58,201	31.0	32.2	1875.6
November	58,163	24.7	40.5	2357.1
December	58,101	28.2	35.4	2058.3
January	57,773	25.8	38.7	2237.3
February	56,442	24.5	40.8	2304.3
March*	47,500	27.3	36.6	1739.9
Group G1				
August	59,193	56.4	17.7	1049.9
September	59,138	38.0	26.3	1557.5
October	59,102	28.4	35.2	2082.6
November	59,065	24.7	40.5	2394.3
December	59,016	29.3	34.1	2014.6
January	58,963	26.2	38.1	2248.7
February	58,931	25.8	38.8	2288.7
March*	52,786	25.4	39.4	2317.5

*Estimated from displacement measurements in liberation trucks.

Appendix A (cont).

Year, Group	Number of Fish	Fish/kg	g/Fish	Total kg
1992-1993				
Group G2				
August	59,059	52.2	19.2	1132.5
September	59,002	39.2	25.2	1485.5
October	58,976	31.1	32.2	1897.6
November	58,950	26.0	38.5	2268.2
December	58,924	26.2	38.2	2249.5
January	58,685	26.7	37.5	2199.3
February	57,676	24.6	40.6	2340.3
March*	49,191	28.7	34.8	1711.8
1993-1994				
Group A1				
August	39,563	89.2	11.2	443.7
September	39,524	52.0	19.2	759.5
October	39,492	40.3	24.8	980.0
November	39,474	44.8	22.3	880.9
December	39,462	36.1	27.7	1093.7
January	39,407	36.3	27.5	1084.3
February*	38,955	34.9	28.7	1118.0
Group A2				
August	39,511	78.7	12.7	501.8
September	39,487	46.1	21.7	856.9
October	39,441	34.2	29.2	1151.7
November	39,393	35.1	28.5	1122.7
December	39,362	37.3	26.8	1054.9
January	39,331	36.0	27.8	1093.4
February*	36,525	33.1	30.2	1103.1
Group B1				
August	39,511	78.7	12.7	501.8
September	39,487	46.1	21.7	856.9
October	39,441	34.2	29.2	1151.7
November	39,393	35.1	28.5	1122.7
December	39,362	37.3	26.8	1054.9
January	39,331	36.0	27.8	1093.4
February*	36,525	33.1	30.2	1103.1

*Estimated from displacement measurements in liberation trucks.

Appendix A (cont.)

Year, Group	Number of Fish	Fish/kg	g/Fish	Total kg
1993-1994				
Group B2				
August	19,968	86.8	11.6	231.6
September	19,932	39.2	25.5	508.3
October	19,903	37.6	26.6	529.4
November	19,872	36.4	27.5	546.5
December	19,842	31.9	31.3	621.1
January	19,814	31.1	32.2	638.0
February*	17,550	28.6	35.0	614.3
Group C1				
August	39,612	97.3	10.3	407.1
September	39,592	50.6	19.8	783.0
October	39,558	35.6	28.1	1110.7
November	39,525	36.8	27.2	1074.2
December	39,506	35.7	28.0	1105.2
January	39,475	29.9	33.5	1321.5
February*	36,704	32.5	30.8	1129.4
Group C2				
August	38,904	85.5	11.7	455.2
September	38,853	45.2	22.1	858.7
October	38,826	37.7	26.5	1028.9
November	38,785	37.5	26.7	1035.6
December	38,738	33.3	30.0	1162.1
January	38,706	32.5	30.8	1192.1
February*	33,082	30.5	32.8	1085.1
Group D1				
August	116,808	113.0	8.8	1033.4
September	116,742	59.4	16.8	1966.8
October	116,642	40.7	24.5	2863.2
November	116,519	44.4	22.5	2627.2
December	116,442	40.9	24.4	2846.7
January	116,355	37.0	27.0	3147.1
February*	116,110	37.4	26.7	3104.5

*Estimated from displacement measurements in liberation trucks.

Appendix A (cont.)

Year, Group	Number of Fish	Fish/kg	g/Fish	Total kg
1993-1994				
Group D2				
August	116,768	91.7	10.9	1272.8
September	116,628	51.8	19.3	2250.9
October	116,528	37.0	27.0	3146.8
November	116,408	38.6	25.9	3015.0
December	116,347	38.2	26.2	3048.3
January	116,286	35.1	28.5	3314.2
February*	108,378	35.8	27.9	3023.7
Group E1				
August	59,551	100.0	10.0	595.5
September	59,489	61.3	16.3	969.7
October	59,432	48.3	20.7	1230.2
November	59,401	44.1	22.7	1348.4
December	59,372	51.8	19.3	1145.9
January	59,346	49.5	20.2	1198.8
February*	44,505	47.4	21.1	938.9
Group E2				
August	59,014	87.8	11.4	672.9
September	58,997	54.3	18.4	1085.7
October	58,966	45.2	22.1	1303.3
November	58,951	49.0	20.4	1202.7
December	58,935	41.3	24.2	1426.4
January	58,926	34.2	29.2	1720.8
February*	41,760	38.2	26.2	1093.2
Group F1				
August	58,961	85.5	11.7	689.8
September	58,932	51.8	19.3	1137.4
October	58,877	40.0	25.0	1471.9
November	58,831	38.0	26.3	1547.3
December	58,791	35.0	28.6	1681.4
January	58,747	40.5	24.7	1451.1
February*	50,460	38.3	26.1	1317.0

*Estimated from displacement measurements in liberation trucks.

Appendix A (cont.)

Year, Group	Number of Fish	Fish/kg	g/Fish	Total kg
1993-1994				
Group F2				
August	59,023	89.7	11.1	658.0
September	59,010	50.9	19.6	1159.4
October	58,982	43.4	23.0	1359.4
November	58,969	42.1	23.7	1400.4
December	58,950	44.2	22.6	1335.1
January	58,934	31.8	31.4	1853.3
February*	49,077	37.6	26.6	1305.2
Group G1				
August	59,696	102.0	9.8	585.0
September	58,667	58.5	17.1	1020.3
October	58,608	45.7	21.9	1305.4
November	58,578	45.9	21.8	1298.8
December	58,543	41.8	23.9	1423.1
January	58,508	35.3	28.3	1684.1
February*	53,235	37.2	26.9	1431.0
Group G2				
August	59,674	104.5	9.6	571.2
September	58,665	58.6	17.1	1018.6
October	58,606	45.1	22.2	1321.6
November	58,584	44.9	22.3	1327.1
December	58,559	44.3	22.6	1344.4
January	58,541	38.4	26.1	1552.4
February*	51,136	41.3	24.2	1238.2

*Estimated from displacement measurements in liberation trucks.

APPENDIX B

Ammonium Concentrations (micrograms per liter) for
Experimental Raceways at Willamette Hatchery, 1990-1994.

Year, date	Inflow	Inflow	A1	A2	B1	B2	C1	C2	D1	D2	Inflow	Inflow	E1	E2	F1	F2	G1	G2
1990-1991 Rearing Year																		
08/05/90	0.00		0.08		0.02		0.07		0.38		0.02		0.08		0.36		0.37	
08/12/90	0.00		0.06		0.04		0.11		0.21		0.03		0.07		0.19		0.33	
08/19/90	0.09		0.07		0.04		0.06		0.22		0.01		0.08 .		0.23		0.41	
08/26/90	0.06		0.08		0.01		0.07		0.20		0.08		0.07		0.22		0.33	
09/02/90	0.05		0.10		0.07		0.08		0.16		0.04		0.10		0.20		0.44	
09/09/90	0.02		0.08		0.06		0.10		0.14		0.02		0.08		0.14		0.35	
09/16/90	0.00		0.08		0.06		0.07		0.09		0.06		0.08		0.13		0.19	
09/23/90	0.02		0.01		0.8		0.06		0.11		--		0.06		0.13		0.21	
09/30/90	0.04		0.08		0.01		0.08		0.07		0.02		0.07		0.15		0.20	
10/07/90	0.00		0.00		0.01		0.02		0.07		0.01		0.02		0.08		0.12	
10/14/90	0.92		0.12		0.08		0.08		0.14		0.03		0.07		0.18		0.34	
10/21/90	0.92		0.06		0.06		0.07		0.11		0.01		0.06		0.14		0.29	
10/28/90	--		0.03		0.04		0.06		0.10		0.01		0.03		0.12		0.24	
11/04/90	0.04		0.07		0.05		0.06		0.16		0.00		0.08		0.23		0.27	
11/11/90	0.03		0.17		0.08		0.09		0.30		0.03		0.09		0.26		0.30	
11/18/90	0.06		0.06		0.01		0.12		0.31		0.12		0.16		0.27		0.43	
11/25/90	0.01		0.11		0.07		0.11		0.37		0.01		0.09		0.16		0.11	
12/02/90	0.00		0.15		0.06		0.08		0.28		0.00		0.07		0.18		0.33	
12/09/90	0.01		0.12		0.04		0.12		0.27		0.01		0.06		0.16		0.25	
12/16/90	0.04		0.11		0.07		0.12		0.20		0.00		0.08		0.17		0.24	

Appendix B (cont.)

Year, date	Inflow	Inflow	A1	A2	B1	B2	C1	C2	D1	D2	Inflow	Inflow	E1	E2	F1	F2	G1	G2
1990-1991 Rearing Year																		
12/23/90	0.02		0.11		**0.06**		**0.07**		0.29		0.07		**0.06**		0.17		0.27	
12/30/90	**0.00**		0.06		0.06		**0.08**		**0.20**		0.03		**0.08**		0.19		**0.29**	
01/06/91	0.03		0.07		**0.05**		**0.06**		0.12		0.83		**0.05**		**0.08**		**0.16**	
01/13/91	0.01		0.01		0.01		0.00		0.11		**0.00**		0.02		0.06		0.11	
01/20/91	**0.05**		0.11		0.05		0.10		0.13		**0.04**		**0.08**		0.17		0.27	
01/27/91	0.06		**0.08**		**0.09**		*0.87*		0.13		0.01		0.13		**0.19**		0.27	
02/03/91	**0.03**		*0.07*		*0.06*		**0.08**		0.15		0.82		0.07		0.1s		**0.21**	
02/10/91	0.03		0.14		0.86		**0.09**		**0.14**		0.02		**0.09**		0.27		0.31	
02/17/91	**0.02**		0.13		0.87		0.16		0.31		**0.02**		0.12		0.29		0.39	
02/24/91	**0.01**		**0.15**		0.07		0.10		0.30		0.02		**0.09**		**0.21**		0.44	
1991-1992 Rearing Year																		
08/06/91	0.00	**0.03**	0.15	**0.23**	0.12	0.14	0.26	0.16	0.36	**0.54**	**0.07**	0.03	**0.16**	0.17	**0.39**	0.39	**0.68**	**0.58**
08/13/91	--	**0.00**	--	0.17	--	0.10	--	0.13	--	**0.40**	**0.01**	--	0.13	--	0.37	--	0.42	--
08/20/91	0.01	0.82	0.21	0.18	**0.07**	0.13	0.13	0.18	0.30	0.42	0.09	**0.02**	D-17	0.17	0.50	**0.49**	**0.70**	0.64
08/27/91	0.02	0.02	**0.15**	**0.21**	**0.09**	0.12	0.15	**0.21**	**0.33**	**0.49**	0.02	**0.02**	**0.24**	0.88	0.50	**0.20**	0.67	0.41
09/03/91	**0.00**	**0.03**	0.15	**0.23**	0.10	**0.14**	0.18	0.20	0.12	0.46	0.00	**0.00**	0.13	0.10	0.31	0.27	0.32	**0.36**
09/10/91	**0.00**	**0.03**	0.28	0.19	**0.06**	0.12	0.27	0.17	0.43	0.34	**0.03**	**0.03**	0.12	0.12	0.43	0.37	0.62	**0.45**
09/17/91	0.01	0.03	**0.09**	**0.23**	**0.08**	0.19	0.11	0.12	**0.30**	0.33	0.01	0.01	0.11	**0.06**	**0.35**	0.15	0.34	0.32
09/24/91	0.03	--	0.25	--	0.15	--	0.15	--	0.32	--	--	0.03	--	0.12	--	**0.40**	--	0.36
10/01/91	0.02	**0.01**	0.19	0.24	o-14	**0.18**	0.19	0.17	0.32	0.46	**0.02**	0.01	0.12	0.12	0.36	0.33	0.5	**0.46**
10/08/91	0.01	**0.03**	0.23	0.13	0.14	**0.09**	**0.20**	0.22	0.40	0.62	**0.03**	**0.04**	0.13	0.20	**0.40**	0.42	**0.59**	0.34
10/15/91	**0.04**	**0.00**	0.19	0.14	0.17	**0.06**	**0.20**	0.11	**0.48**	0.27	**0.00**	**0.05**	0.10	0.10	0.29	0.39	0.32	**0.40**
10/22/91	0.03	**0.01**	0.14	**0.08**	0.10	**0.08**	0.14	0.10	0.30	0.13	**0.02**	**0.01**	0.11	**0.09**	0.23	0.22	0.42	0.37
10/29/91	--	**0.01**	--	0.10	--	0.04	0.10	--	0.38	**0.00**	--	**0.05**	--	0.2s	--	0.35	--	--
11/12/91	**0.01**	**0.05**	**0.08**	0.14	0.07	0.12	**0.09**	0.14	**0.16**	0.24	0.63	**0.02**	0.17	**0.08**	0.32	0.19	0.44	**0.30**
11/19/91	0.01	**0.02**	0.12	0.14	**0.05**	**0.08**	0.20	0.86	0.24	0.19	0.01	0.02	**0.09**	0.10	--	0.32	0.31	0.43

Appendix B (cont.)

Year, date	Inflow	Inflow	A1	A2	B1	B2	C1	C2	D1	D2	Inflow	Inflow	E1	E2	F1	F2	C1	G2
1991-1992 Rearing Year																		
11/26/91	--	0.04	--	0.14	--	0.12	--	0.08	--	0.25	--	0.04	--	0.17	--	0.22	--	0.33
12/03/91	0.02	0.03	0.10	0.12	0.10	0.08	0.10	0.10	0.16	0.21	0.03	0.00	0.07	0.11	0.14	0.22	0.27	0.34
12/10/91	0.02	0.02	0.17	0.13	0.07	0.06	0.07	0.07	0.15	0.16	0.00	0.02	0.12	0.13	0.27	0.25	0.45	0.33
12/17/91	--	0.02	--	0.07	--	0.05	--	0.07	--	0.15	--	0.01	--	0.10	--	0.17	--	0.27
12/24/91	0.02	--	0.08	--	0.06	--	0.05	--	0.14	--	0.03	--	0.06	--	0.15	--	0.20	--
12/31/91	0.02	0.02	0.11	0.09	0.07	0.05	0.06	0.04	0.10	0.10	0.02	0.01	0.07	0.08	0.19	0.16	0.22	0.23
01/07/92	0.01	0.02	0.09	0.09	0.04	0.05	0.04	0.05	0.07	0.08	0.01	0.03	0.06	0.06	0.10	0.16	0.20	0.20
01/14/92	0.01	0.00	0.05	0.07	0.05	0.05	0.05	0.07	0.11	0.09	0.01	0.01	0.06	0.06	0.15	0.16	0.24	0.23
01/21/92	0.01	0.00	0.06	0.07	0.04	0.03	0.01	0.05	0.07	0.14	0.00	0.00	0.06	0.08	0.12	0.21	0.17	0.25
01/28/92	0.03	0.02	0.12	0.16	0.07	0.13	0.10	0.13	0.16	0.19	0.02	0.02	0.09	0.16	0.26	0.26	0.36	0.40
02/04/92	0.00	0.01	0.03	0.08	0.02	0.04	0.05	0.05	0.11	0.13	0.01	0.00	0.09	0.07	0.15	0.19	0.31	0.31
02/11/92	0.02	0.02	0.20	0.15	0.12	0.10	0.14	0.11	0.40	0.25	0.01	0.02	0.16	0.10	0.33	0.21	0.57	0.37
02/18/92	0.01	--	0.08	--	0.07	--	0.10	--	0.15	--	0.04	--	0.08	--	0.15	--	0.23	--
02/25/92	0.01	--	0.12	--	0.07	--	0.10	--	0.12	--	0.01	--	0.06	--	0.16	--	0.26	--
1992-1993 Rearing Year																		
08/04/92	0.02		0.23		0.08		0.12		0.26									
08/08/92		0.01		0.20		0.07		0.10		0.52		0.00		0.07		0.25		0.36
08/11/92	0.03		0.16		0.15		0.13		0.35		0.02		0.07		0.26		0.47	
08/18/92												0.03		0.17		0.45		0.59
08/25/92	0.01		0.26		0.11		0.22		0.56									
08/27/92		0.02		0.29		0.17		0.13		0.62		0.04		0.23		0.42		0.78
09/01/92	0.03		0.16		0.06		0.09		0.56		0.04		0.17		0.56		0.61	
09/03/92		0.0)		0.24		0.15		0.14		0.51		0.03		0.29		0.39		0.50
09/08/92	0.01		0.17		0.03		0.11		0.38				0.17		0.31		0.54	
09/10/92		0.01		0.12		0.08		0.06		0.39		0.01		0.26		0.44		0.56

Appendix B (cont.)

Year, date	Inflow	Inflow	A1	A2	B1	B2	C1	C2	D1	D2	Inflow	Inflow	E1	E2	F1	F2	G1	G2
1992-1993 Rearing Year																		
09/15/92	0.02		0.20		0.08		0.12		0.37		0.00		0.09		0.23		0.27	
w/17/92		0.03		0.19		0.14		0.14		0.31		0.03		0.18		0.32		0.51
09/22/92	0.01		0.29		0.16		0.17		0.53		0.03		0.16		0.26		0.47	
09/24/92		0.07		0.21		0.14		0.15		0.34		0.02		0.15		0.26		0.41
09/29/92											0.02		0.16		0.36		0.56	
10/01/92		0.02		0.19		0.12		0.13		0.34		0.02		0.22		0.37		0.62
10/06/92	0.03		0.11		0.06		0.10		0.24									
10/08/92		0.01		0.15		0.09		0.12		0.33		0.01		0.22		0.32		0.44
10/13/92	0.01		0.17		0.12		0.15		0.41		0.03		0.15		0.28		0.40	
10/15/92		0.02		0.14		0.10		0.12		0.41		0.02		0.17		0.23		0.40
10/20/92	0.02		0.09		0.07		0.07		0.28		0.01		0.13		0.40		0.50	
10/22/92		0.03		0.16		0.12		0.15		0.41		0.01		0.17		0.36		0.56
10/27/92	0.03		0.10		0.07		0.10		0.26		0.03		0.12		0.16		0.30	
10/29/92		0.01		0.10		0.07		0.13		0.42		0.01		0.19		0.37		0.50
11/03/92	0.02		0.08		0.03		0.06		0.18		0.00		0.16		0.31		0.37	
11/05/92		0.00		0.04		0.02		0.01		0.17		0.00		0.10		0.23		0.35
11/10/92	0.02		0.11		0.07		0.14		0.29		0.03		0.08		0.19		0.23	
11/12/92		0.01		0.09		0.07		0.09		0.34		0.01		0.14		0.26		0.39
11/17/92	0.03		0.10		0.08		0.09		0.35		0.03		0.14		0.16		0.32	
11/19/92		0.00		0.04		0.05		0.03		0.11		0.01		0.06		0.13		0.16
11/24/92	0.02		0.06		0.04		0.06		0.14		0.01		0.16		0.20		0.24	
12/01/92	0.00		0.06		0.05		0.09		0.11		0.03		0.06		0.17		0.27	
12/03/92		0.04		0.09		0.06		0.10		0.16		0.04		0.11		0.20		0.24
12/08/92	0.01		0.05		0.06		0.07		0.13		0.01		0.08		0.12		0.32	
12/10/92		0.05		0.11		0.08		0.08		0.19		0.01		0.06		0.14		0.23

Appendix B (cont.)

Year, date	Inflow	Inflow	A1	A2	B1	B2	C1	C2	D1	D2	Inflow	Inflow	E1	E2	F1	F2	G1	G2
1992-1993 Rearing Year																		
12/15/92											0.01		0.08		0.14		0.23	
12/17/92		0.02		0.07		0.06		0.05		0.11		0.01		0.06		0.15		0.17
12/22/92	0.03		0.07		0.04		0.08		0.16									
12/24/92		0.00		0.08				0.06		0.16		0.02		0.08		0.16		0.27
12/28/92	0.03		0.10		0.06		0.09		0.18		0.03		0.06		0.14		0.25	
12/30/92		0.04		0.10		0.06		0.09		0.24		0.01		0.08		0.19		0.24
01/05/93											0.01		0.10		0.21		0.26	
01/12/93	0.00		0.04		0.03		0.03		0.11									
01/14/93		0.01		0.05		0.02		0.03		0.07		0.01		0.03		0.10		0.15
01/19/93	0.01		0.03		0.01		0.03		0.09		0.02		0.06		0.12		0.13	
01/21/93		0.0)		0.09		0.06		0.09		0.26		0.06		0.10		0.12		0.21
01/26/93	0.02		0.04		0.03		0.06		0.19		0.00		0.01		0.09		0.13	
01/28/93		0.04		0.12		0.07		0.11		0.17		0.01		0.16		0.23		0.31
02/02/93	0.03		0.12		0.04		0.15		0.20		0.01		0.8		0.11		0.16	
02/04/93		0.03		0.12		0.04		0.08		0.22		0.01		0.08		0.13		0.19
02/09/93	0.02		0.11		0.06		0.07		0.20		0.03		0.12		0.24		0.31	
02/11/93		0.00		0.07		0.06		0.06		0.08		0.01		0.06		0.13		0.23
02/16/93	0.00		0.10		0.02		0.03		0.11		0.02		0.09		0.16		0.28	
02/18/93		0.02		0.05		0.04		0.8		0.07		0.01		0.06		0.11		0.15
02/23/93											0.01		0.01		0.07		0.16	
03/02/93	0.02		0.01		0.02		0.03		0.16									
03/04/93		0.03		0.13		0.09		0.08		0.17		0.03		0.09		0.13		0.22
03/09/93	0.02		0.07		0.07		0.08		0.16		0.04		0.06		0.12		0.21	

Appendix B (cont.)

Year, date	Inflow	Inflow	A1	A2	B1	B2	C1	C2	D1	D2	Inflow	Inflow	E1	E2	F1	F2	D1	G2
1993-1994 Rearing Year																		
08/03/93	0.05		0.11		**0.08**		0.07		0.19		0.04		**0.09**		0.29		0.32	
08/05/93		**0.00**		0.12		**0.04**		0.06		0.29		**0.00**		0.63		0.13		**0.26**
08/10/93	**0.02**		0.12		**0.08**		0.10		0.13		**0.05**		0.12		0.23		0.37	
08/12/93		**0.02**		0.13		0.07		0.14		0.27		0.06		0.12		**0.25**		0.42
08/17/93	0.02		**0.21**		0.10		0.12		**0.21**		0.03		0.14		**0:27**		**0.49**	
08/19/93		**0.03**		**0.15**		0.06		0.13		**0.36**		**0.00**		0.14		0.33		0.52
08/24/93	0.03		0.14		**0.09**		**0.09**		0.19		**0.03**		0.14		**0.28**		0.41	
08/26/93		0.02		0.14		0.07		**0.09**		**0.20**		0.05		0.12		0.22		**0.35**
08/31/93	0.0)		**0.30**		0.15		0.12		0.17		**0.07**		0.17		**0.38**		*0.57*	
09/02/93		0.02'		0.17		0.07		0.12		0.37		**0.00**		0.23		**0.23**		0.42
09/07/93	0.01		0.11		0.11		0.07		0.30		0.02		0.15		0.34		**0.48**	
09/09/93		0.03		0.20		0.15		0.11		**0.49**		0.02		**0.18**		0.43		0.60
09/14/93	0.03		0.19		0.13		0.11		**0.28**		**0.03**		0.16		**0.33**		0.44	
09/16/93		0.02		0.16		**0.09**		0.14		0.22		**0.01**		0.14		**0.21**		0.31
09/21/93	0.01		**0.08**		0.01		0.07		0.13		**0.01**		0.11		0.11		**0.28**	
09/23/93		0.01		0.10		‘0.06		0.10		0.19		0.01		0.10		0.19		**0.23**
09/28/93	**0.00**		0.16		0.11		0.14		0.25		0.02		0.17		0.37		0.51	
09/30/93		0.03		0.11		0.11		0.12		0.46		0.05		**0.16**		0.32		**0.36**
10/05/93	**0.01**		**0.17**		**0.08**		**0.10**		**0.24**		**0.01**		**0.15**		**0.23**		**0.43**	
10/07/93		0.04		0.16		0.12		0.13		0.53		**0.04**		**0.16**		**0.26**		**0.40**
10/12/93	**0.00**		0.23		0.10		0.10		**0.23**		**0.02**		0.11		0.37		0.55	
10/14/93		**0.01**		0.17		0.11		**0.09**		0.43		0.01		**0.18**		**0.28**		0.41
10/19/93	0.01		0.11		0.01		0.07		0.15		0.01		0.06		0.16		0.24	
10/21/93		0.02		0.15		0.05		0.13		0.31		0.03		0.13		0.19		0.32
10/26/93	**0.02**		0.15		**0.08**		**0.09**		0.14		**0.03**		0.10		0.27		0.53	

Appendix B (cont.)

Year, date	Inflow	Inflow	A1	A2	B1	K	C1	C2	D1	D2	Inflow	Inflow	E1	E2	F1	F2	C1	G2
1993-1994 Rearing Year																		
10/28/93		0.02		0.17		0.08		0.14		0.30		0.02		0.13		0.19		0.28
11/02/93	0.02		0.10		0.04		0.03		0.10		0.01		0.08		0.12		0.22	
11/04/93		0.02		0.07		0.01		0.09		0.20 .		0.01		0.07		0.12		0.25
11/09/93	0.04		0.08		0.01		0.10		0.13		0.04		0.06		0.11		0.13	
11/11/93		0.04		0.08		0.06		0 . 0 6		0.11		0.01		0.09		0.11		0.13
11/16/93	0.00		0.09		0.06		0.06		0.14		0.01		0.08		0.17		0.19	
11/18/93		0.01		0.09		0.08		0.10		0.09		0.0)		0.10		0.17		0.18
11/22/93	0.03		0.8		0.03		0.02		0.06		0.01		0.05		0.10		0.12	
11/24/93		0.01		0.01		0.03		0.04		0.17		0.00		0.03		0.12		0.13
11/30/93	0.02		0.07		0.02		0.03		0.09		0.00		0.03		0.09		0.14	
12/02/93		0.02		0.07		0.05		0.10		0.10		0.02		0.07		0.12		0.17
12/08/93	0.01		0.08		0.01		0.08		0.17		0.04		0.13		0.18		0.17	
12/10/93		0.06		0.07'		9.06		0 . 0 6		0.10		0.01		0.07 .		0.14		0.16
12/14/93	0.00		0.06		0.04		0.04		0.10		0.02		0.06		0.12		0.18	
12/16/93		0.03		0.08		0.09		0.04		0.11		0.03		0.03		0.13		0.18
01/11/94	0.03		0.07		0.08		0.06		0.13		0.0)		0.07		0.13		0.31	
01/13/94		0.09		0.19		0.17		0.15		0.19		0.01		0.13		0.21		0.32
01/18/94	0.03		0.06		0.04		0.02		0.03		0.02		0.04		0.06		0.10	
01/20/94		0.03		0.06		0.08		0.08		0.14		0.05		0.13		0.16		0.21
01/25/94	0.02		0.09		0.05		0.02		0.07		0.00		0.01		0.12		0.21	
01/27/94		0.03		0.06		0.04		0.06		0.11		0.01		0.06		0.10		0.11
02/01/94	0.02		0.03		0.03		0.02		0.02		0.02		0.03		0.8		0.06	
02/03/94		0.00		0.01		0.05		0.03		0.08		0.03		0.10		0.17		0.17
02/08/94	0.00		0.05		0.02		0.02		0.03		0.00		0.04		0.10		0.14	
02/10/94		0.00		0.06		0.00		0.01		0.04		0.01		0.03		0.06		0.06
02/15/94	0.02		0.12		0.09		0.06		0.08		0.02		0.01		0.18		0.25	
02/17/94		0.01		0.10		0.06		0.07		0.13		0.01		0.09		0.17		0.23

APPENDIX C

Temperatures and pHs for Experimental Raceways at Willamette Hatchery, 1990-1994.

		pH																	
Year, date	Ave Temp	Inflow	Inflow	A1	A2	B1	B2	C1	C2	D1	D2	Inflow	Inflow	E1	E2	F1	F2	G1	G2
1990-1991 Rearing Year																			
09/23/90	11.9	7.88	7.92	7.53	7.68	7.67	7.U	7.22	7.42	6.92	7.15	7.88	7.88	7.51	7.61	7.11	7.21	6.95	6.92
09/30/90	11.7		7.77		7.46		7.66		7.39		7.19		7.66		7.32		7.24		7.01
10/07/90	7.5		8.02		7.63		7.91		7.59		7.34		8.04		7.62		7.39		7.20
10/14/90	8.6	8.06		7.62		7.79		7.66		7.36		6.03		7.73		7.51		7.29	
10/28/90	8.1	7.n	7.n	7.52	7.61	7.62	7.63	7.45	7.56	7.39	7.54	7.66	7.U	7.53	7.59	7.31	7.56	7.11	7.50
11/04/90	7.8		7.47		7.20		7.26		7.17		6.98	7.33		7.15		7.05		6.26	
11/11/90	6.4	7.52	7.39	7.33	7.37	7.41	7.46	7.30	7.29	7.16	7.12	7.47	7.51	7.20	7.39	7.14	7.a	7.07	7.20
11/18/90	6.4	7.49	7.69	7.26	7.53	7.37	7.59	7.21	7.44	7.13	7.35	7.72	7.52	7.59	7.37	7.46	7.27	7.27	7.13
11/25/90	5.6	7.46	7.54	7.25	7.40	7.28	7.44	7.13	7.36	7.11	7.25	7.56	7.39	7.43	7.26	7.37	7.15	7.27	7.07
12/02/90	4.7	7.62	7.81	7.51	7.63	7.66	7.62	7.51	7.64	7.20	7.51	7.73	7.73	7.53	7.56	7.37	7.24	7.21	7.m
12/09/90	5.0	7.65	7.78	7.45	7.53	7.49	7.66	7.46	7.46	7.00	7.32	7.76	7.46	7.51	7.W	7.34	7.01	7.17	6.90
12/16/90	4.7	7.67		7.46		7.60		7.45		7.34			7.54		7.47		7.36		7.34
12/23/90	0.6		7.85		1.60		7.71		7.55		7.40	7.81		7.51		7.40		7.27	
12/30/90	0.6	7.71		7.59		7.66		7.52		7.41			7.81		7.74		7.56		7.46
01/06/91	2.2		7.73		7.u		7.51		7.35		7.26	7.59		7.36		7.29		7.15	
01/13/91	5.3	7.w	7.55	7.21	7.32	7.30	7.43	7.15	7.27	7.05	7.12	7.66	7.51	7.44	7.31	7.26	7.10	7.12	6.99
01/20/91	3.6	7.71	7.62	7.54	7.49	7.56	7.54	7.54	7.36	7.25	7.17	7.64	7.70	7.42	7.50	7.16	7.43	6.96	7.12
01/27/91	2.2	7.R	7.57	7.42	7.59	7.54	7.49	7.33	7.53	7.25	7.40	7.67	7.77	7.60	7.71	7.41	7.63	7.26	7.20
02/03/91	5.3	7.66	7.40	7.54	7.19	7.57	7.26	7.56	7.09	7.45	6.93	7.40	7.49	7.29	7.41	7.22	7.32	6.80	7.41
02/10/91	4.7	7.47	7.57	7.27	7.35	7.36	7.39	7.19	7.32	6.W	7.14	7.64	7.27	7.56	7.10	7.36	6.97	7.11	6.80
02/17/91	5.6	7.61		7.42		7.50		7.34		6.61		7.59		7.42		7.10		6.73	

Appendix c (cont.)

Year, date	Ave Temp	pH																	
		Inflow	Inflow	A1	A2	B1	B2	C1	C2	D1	D2	Inflow	Inflow	E1	E2	F1	F2	G1	G2
1991-1992 Rearing Year																			
08/06/91	14.7	7.46	7.55	7.39	7.39	7.32	7.u	7.36	7.34	7.35	7.31	7.52	7.43	7.46	7.u	7.w	7.42	7.36	7.w
08/13/91	14.2		7.84		7.61		7.72		7.53		7.34	7.87		7.73		7.46		7.3	
08/20/91	15.9	7.83	7.67	7.57	7.66	7.63	7.76	7.W	7.61	7.32	7.33	7.88	7.65	7.73	7.54	7.41	7.35	7.25	7.23
08/27/91	12.2	7.71	8.07	7.77	7.75	7.87	7.92	7.67	7.70	7.38	7.32	8.03	7.96	7.67	7.68	7.40	7.23	7.12	7.16
09/03/91	13.4	7.w	8.02	7.61	7.72	7.75	7.82	7.46	7.64	7.30	7.35	8.06	7.96	7.84	7.w	7.w	7.38	7.25	7.24
09/10/91	12.3	8.03	7.97	7.71	7.71	7.82	7.77	7.60	7.66	7.40	7.42	8.01	8.04	7.88	7.80	7.59	7.56	7.31	7.37
09/17/91	12.3	7.96	8.01	7.67	7.75	7.77	7.82	7.53	7.62	7.38	7.28	7.w	7.99	7.81	7.87	7.w	7.w	7.24	7.41
09/24/91	11.7	7.91		7.70		7.72		7.64		7.46			8.03		7.85		7.61		7.41
10/01/91	11.4	7.w	7.90	7.63	7.65	7.72	7.W	7.55	7.55	7.42	7.34	7.95	7.98	7.6	7.90	7.59	7.58	7.37	7.37
10/08/91	9.7	7.96	7.90	7.68	7.66	7.76	7.R	7.63	7.60	7.46	7.36	7.95	8.00	7.81	7.82	7.33	7.61	7.23	7.31
10/15/91	9.2	8.00	8.05	7.w	7.80	7.76	7.90	7.60	7.71	7.42	7.42	8.05	8.05	7.w	7.79	7.38	7.53	7.17	7.35
10/22/91	a.4	7.97	7.94	7.66	7.77	7.72	7.66	7.62	7.72	7.39	7.51	7.96	8.00	7.71	7.76	7.43	7.50	7.P	7.31
11/05/91	--		7.62		7.45		7.54		7.40		7.m	7.w		7.47		7.20		6.96	
11/12/91	9.7	7.47	7.70	7.34	7.46	7.36	7.60	7.28	7.34	6.98	7.20	7.59	7.60	7.49	7.44	7.32	7.19	7.11	6.01
11/19/91	8.1	7.62	7.53	7.46	7.30	7.53	7.38	7.39	7.28	7.23	7.14	7.61	7.59	7.39	7.56	7.32	7.36	7.10	7.16
11/26/91	7.3		7.35		7.27		7.28		7.23		7.02		7.28		7.22		7.12		6.98
12/03/91	7.0	7.70	7.59	7.u	7.43	7.48	7.49	7.w	7.38	7.29	7.28	7.66	7.72	7.53	7.54	7.38	7.36	7.22	7.22
12/10/91	6.4	7.62	7.57	7.36	7.40	7.56	7.47	7.32	7.37	7.21	7.24	7.67	7.55	7.47	7.46	7.33	7.36	7.16	7.20
12/17/91	6.2		7.56		7.u		7.50		7.w		7.26		7.56		7.52		7.41		7.23
12/24/91	--	7.66		7.48		7.54		7.44		7.35		7.76		7.66		7.43		7.50	
12/31/91	4.4	7.61	7.71	7.56	7.55	7.50	7.64	7.42	7.53	7.38	7.43	7.65	7.6	7.55	7.74	7.46	7.45	7.37	7.36
01/07/92	4.6	7.n	7.w	7.56	7.74	7.63	7.w	7.61	7.75	7.45	7.55	7.94	7.90	7.71	7.99	7.46	7.44	7.28	7.31
01/14/92	5.6	7.66	7.n	7.64	7.56	7.67	7.61	7.58	7.53	7.42	7.46	7.96	7.89	7.57	7.73	7.45	7.42	7.29	7.27
01/21/92	5.0	7.w	7.63	7.57	7.62	7.67	7.79	7.43	7.59	7.37	7.39	7.90	7.93	7.77	7.82	7.52	7.55	7.37	7.28
01/28/92	6.7	7.94	7.n	7.57	7.54	7.64	7.63	7.56	7.53	7.37	7.37	7.94	7.92	7.72	7.64	7.50	7.44	7.31	7.24

Appendix *c* (cont.)

Year, date	Ave Temp	Inflow	Inflow	A1	A2	B1	K	C1	C2	D1
		pH								
1991-1992 Rearing Year										
02/04/92	4.8	7.84	7.n	7.59	7.40	7.74	7.65	7.51	7.58	7.38
02/11/92	6.7	7.74	7.86	7.53	7.62	7.60	7.72	7.46	7.60	7.31
02/18/92	--	7.85		7.59		7.67		7.50		7.31
02/25/92	--	7.76		7.50		7.61		7.53		7.17
1992-1993 Rearing Year										
08/04/92	16.3	7.98		7.71		7.81		7.63		7.51
08/11/92	15.3	8.01		7.62		7.75		7.56		7.15
08/25/92	14.1	7.80		7.54		7.64		7.46		7.35
08/27/92	14.1		7.87		7.63		7.69		7.58	
09/01/92	14.0	7.89		7.55		7.63		7.50		7.36
09/03/92	14.0		7.90		7.66		7.74		7.63	
09/08/92	12.3	7.84		7.55		7.63		7.50		7.43
09/10/92	13.2		7.97		7.67		7.74		7.60	
w/15/92	10.9	7.93		7.47		7.57		7.40		7.30
Wf 17/92	11.3		7.80		7.58		7.60		7.53	
09/22/92	11.8	7.80		7.58		7.63		7.56		7.40
09/24/92	11.7		7.56		7.37		7.43		7.30	
10/01/92	10.8		7.82		7.51		7.56		7.46	
10/06/92	8.6	7.67		7.56		7.60		7.52		7.31
10/08/92	9.6		7.59		7.43		7.50		7.39	
10/13/92	7.8	7.58		7.33		7.42		7.29		7.19
10/15/92	7.6		7.77		7.51		7.R		7.46	
10/20/92	10.0	7.51		7.39		7.44		7.36		7.32
10/22/92	6.6		7.51		7.35		7.40		7.28	
10/27/92	8.8	7.57		7.48		7.51		7.42		7.38

Year, date	D2	Inflow	Inflow	E1	E2	F1	F2	a1	G2
	pH								
1991-1992 Rearing Year									
02/04/92	7.44	7.92	7.93	7.74	7.83	7.54	7.66	7.27	7.34
02/11/92	7.45	7.85	7.98	7.68	7.23	7.50	7.63	7.27	7.43
02/18/92		7.97		7.82		7.42		7.24	
02/25/92		7.w		7.70		7.26		7.05	
1992-1993 Rearing Year									
08/04/92		7.w		7.w		7.n		7.6	
08/11/92		8.86		7.76		7.37		7.21	
08/25/92		7.84		7.63		7.48		7.38	
08/27/92	7.41		7.99		7.88		7.63		7.47
09/01/92		8.00		7.w		7.61		7.43	
09/03/92	7.47		8.03		7.93		7.73		7.56
09/08/92		7.90		7.83		7.63		7.45	
09/10/92	7.46		8.00		7.90		7.72		7.57
w/15/92		7.99		7.85		7.51		7.34	
Wf 17/92	7.46		7.86		7.82		7.65		7.50
09/22/92		7.84		8.81		7.67		7.43	
09/24/92	7.24		7.0		7.57		7.17		7.36
10/01/92	7.41		7.84		7.79		7.46		7.50
10/06/92		7.62		7.50		7.42		7.32	
10/08/92	7.34		7.62		7.59		7.52		7.41
10/13/92		7.93		7.53		7.29		7.13	
10/15/92	7.u		7.66		7.66		7.58		7.50
10/20/92		7.50		7.54		7.47		7.36	
10/22/92	7.22		7.46		7.39		7.34		7.26
10/27/92		7.58		7.54		7.48		7.33	

Appendix c (cont.)

Year, date	Ave Temp	Inflow	Inflow	A1	A2	B1	B2	C1	C2	D1	D2	Inflow	Inflow	E1	E2	F1	F2	81	G2
		pH																	
1992-1993 **Rearing Year**																			
10/29/92	a.7		7.40		7.25		7.30		7.21		7.17		7.45		7.31		7.27		7.21
11/03/92	8.0	7.45		7.36		7.40		7.34		7.32		7.58		7.48		7.41		7.33	
11/05/92	7.7		7.53		7.46		7.48		7.40		7.31		7.76		7.47		7.41		7.32
11/10/92	5.0	7.56		7.41		7.49		7.36		7.25		7.62		7.48		7.34		7.20	
11/12/92	5.7		7.56		7.42		7.49		7.41		7.23		7.n		7.60		7.48		7.18
11/17/92	7.4	7.58		7.40		7.46		7.36		7.20		7.93		7.53		7.29		7.13	
11/19/92	5.5		7.63		7.46		7.50		7.43		7.25		7.77		7.50		7.35		7.19
11/24/92	5.6	7.46		7.28		7.31		7.25		7.14		7.78		7.68		7.28		7.08	
12/01/92	7.3	7.u		7.30		7.37		7.22		7.16		7.72		7.62		7.23		7.11	
WOW92	5.1		7.42		7.31		7.36		7.26		7.17		7.59		7.35		7.27		7.16
12/08/92	--	7.64		7.35		7.40		7.27		7.17		7.71		7.47		7.30		7.18	
12/10/92	--		7.40		7.30		7.35		7.24		7.15		7.60		7.34		7.24		7.16
12/17/92	--		7.50		7.41		7.46		7.36		7.29		7.51		7.47		7.37		7.29
12/22/92	--	7.37		7.26		7.31		7.22		7.15		7.41		7.31		7.21		7.15	
12/24/92	--		7.45		7.33		7.39		7.30		7.23		7.u		7.43		7.32		7.24
12/29/92	--	7.48		7.34		7.41		7.30		7.24		7.53		7.46		7.34		7.25	
12/30/92	--		7.51		7.38		7.u		7.33		7.27		7.55		7.52		7.40		7.31
01/07/93	. .		7.51		7.43		7.48		7.40		7.35		7.60		7.52		7.45		7.37
01/12/93	--	7.74		7.45		7.69		7.40		7.35		7.58		7.52		7.46		7.36	
01/14/93	--		7.54		7.42		7.47		7.40		7.35		7.57		7.53		7.46		7.35
01/19/93	--	7.50			7.39		7.43	7.35		7.31		7.60		7.49		7.43		7.34	
01/21/93	--		7.38	7.29		7.33		7.26		7.20		7.48		7.w		7.32			7.27
01/26/93	--	7.43		7.29		7.34		7.27		7.23		7.47		7.43		7.36		7.27	
01/28/93	--		7.41		7.31		7.35		7.28		7.25		7.49		7.42		7.34		7.36

Appendix *c* (cont.)

Year, date	Ave Temp	pH																	
		Inflow	Inflow	A1	A2	B1	K	C1	C2	D1	D2	Inflow	Inflow	E1	E2	F1	F2	D1	G2
1992-1993 Rearing Year																			
02/02/93	5.1	7.49		**7.35**		7.40		7.32		7.27		7.57		7.51		**7.44**		7.32	
02/04/93	4.6		**7.38**		**7.30**		7.32		7.27		**7.23**		7.42		7.40		**7.35**		**7.27**
02/09/93	6.0	7.42		7.27		7.31		7.24		**7.20**		**7.48**		**7.44**		**7.35**		**7.23**	,
02/11/93	5.6		7.37		7.30		**7.30**		**7.26**		7.20		**7.35**		**7.35**		7.30		7.K
02/16/93	1.9	7.62		**7.35**		7.39		**7.34**		7.32		7.51		7.w		7.46		**7.36**	
02/18/93	3.8		7.43		7.32		**7.35**		**7.30**		**7.24**		'7.36		**7.35**		7.31		**7.24**
03/02/93	5.2	**7.60**		**7.50**		**7.53**		7.u		7.41		7.w		7.66		**7.55**		7.43	
03/04/93	5.2		**7.38**		7.30		**7.33**		7.29		7.24		7.47		**7.44**		7.37		7.b
03/09/93	5.9	7.30		7.20		**7.23**		7.15		7.12		7.37		**7.33**		7.26		7.17	
Rating **Year 1993-1994**																			
08/03/93	14.1	7.74		7.67		7.w		7.65		**7.63**		**7.81**		**7.79**		**7.69**		7.64	
08/05/93	**16.1**		7.50		**7.38**		7.41		7.33		7.29		7.43		**7.38**		**7.36**		7.32
08/10/93	12.7	7.61		7.47		**7.53**		7.u		7.31		7.66		**7.53**		7.43		7.26	
08/12/93	12.7		**7.91**		7.74		**7.82**		7.67		7.w		7.92		7.27		**7.75**		7.K
08/17/93	12.0	7.w		7.74		7.m		**7.70**		**7.56**		**7.90**		**7.84**		7.66		**7.50**	
08/19/93	11.7		7.92		**7.72**		7.K		7.66		7.49		**7.98**		7.6		7.67		7.51
08/24/93	11.7	**7.70**		7.46		7.57		**7.44**		**7.30**		**7.92**		7.65		7.45		7.26	
08/26/93	10.6		7.67		**7.68**		**7.82**		7.64		**7.54**		7.90		**7.83**		**7.72**		**7.58**
08/31/93	12.0	**7.70**		**7.54**		7.65		**7.48**		**7.35**		7.66		7.52		7.41		7.27	
09/02/93	11.5		*7.n*		7.57		7.66		**7.48**		7.37		7.66		7.63		7.52		**7.40**
09/07/93	13.3	7.m		**7.68**		7.74		**7.60**		7.u		7.92		**7.82**		7.59		7.37	
09/09/93	13.1		7.63		7.w		7.49		7.32		7.20		7.67		7.57		**7.38**		**7.22**
09/14/93	**10.8**	7.54		**7.36**		7.41		7.32		**7.21**		7.64		**7.54**		7.37		7.21	
09/16/93	10.7		**7.70**		**7.53**		7.57		7.w		7.31		**7.79**		7.64		7.47		**7.34**
09/21/93	3.6	7.59		7.43		7.49		**7.40**		7.33		7.58		7.53		7.45		**7.33**	

Appendix c (cont.)

Year, date	Ave Temp	Inflow	Inflow	A1	A2	B1	B2	C1	C2	D1	D2	Inflow	Inflow	E1	E2	F1	F2	81	G2
										pH									
1993-1994 Rearing Year																			
09/23/93	8.1		7.73		7.63		7.75		7.57		7.54		7.88		7.76		7.71		7.62
09/28/93	10.5	7.65		7.67		7.73		7.61		7.54		7.95		7.88		7.71		7.55	
09/30/93	10.3		7.88		7.43		7.50		7.38		7.31		7.90		7.23		7.w		7.41
10/05/93	10.9	7.70		7.57		7.63		7.48		7.34		7.71		7.67		7.51		7.35	
10/07/93	10.5		7.73		7.43		7.53		7.37.		7.22		7.w		7.62		7.51		7.33
10812/93	10.5	7.66		7.36		7.43		7.30		7.16		7.70		7.51		7.31		7.16	
10814/93	9.8		7.66		7.36		7.45		7.30		7.15		7.76		7.56		7.u		7.28
10819/93	8.0	7.24		7.39		7.75		7.40		7.30		7.62		7.52		7.u		7.28	
10/21/93	a.9		7.w		7.61		7.81		7.64		7.30		7.93		7.77		7.52		7.41
10/26/93	7.3	7.66		7.61		7.n		7.64 .		7.43		7.90		7.72		7.52		7.36	
10/28/93	8.1		7.92		7.62		7.w		7.60		7.36		7.94		7.22		7.62		7.45
11/02/93	5.7	7.24		7.52		7.71		7.54		7.41		7.80		7.74		7.52		7.40	
11/04/93	5.2		7.89		7.66		7.81		7.62		7.47		7.99		7.27		7.67		7.51
11/09/93	4.8	7.95		7.65		7.73		7.60		7.52		8.01		7.26		7.69		7.56	
11/11/93	4.4		7.95		7.66		7.74		7.65		7.56		8.00		7.w		7.70		7.59
11/16/93	5.0	8.03		7.71		7.76		7.72		7.60		8.03		7.92		7.72		7.59	
11/18/93	5.5		7.99		7.69		7.74		7.70		7.62		8.00		7.93		7.75		7.60
11/22/93	3.3	7.90		7.66		7.72		7.64		7.59		7.95		7.90		7.79		7.66	
11/24/93	1.2'		7.66		7.69		7.71		7.66		7.62		7.94		7.79		7.x		7.64
11/30/93	5.0	7.82		7.63		7.62		7.63		7.61		8.00		7.78		7.R		7.61	
12/02/93	5.3		7.82		7.59		7.63		7.56		7.56		7.m		7.83		7.71		7.61
12/08/93	5.7	7.52		7.w		7.46		7.34 .		7.18		7.m		7.61		7.24		7.09	
12/14/93	5.3	7.23		7.65		7.75		7.63		7.44		7.66		7.w		7.42		7.30	
12/16/93	4.2		7.84		7.66		7.74		7.67		7.50		7.65		7.70		7.59		7.47
01/11/94	5.8	7.70		7.54		7.56		7.50		7.41		7.74		7.67		7.54		7.w	

Appendix c (cont.)

Year, date	Ave Temp	Inflow	Inflow	Al	A2	B1	B2	Cl	C2	D1	D2	Inflow	Inflow	El	E2	F1	F2	al	G2
										pH									
1993-1994 Rearing Year																			
01/13/94	4.8		7.67		7.48		7.53		7.45		7.37		7.78		7.68		7.54		7.39
01/18/94	3.8	7.71		7.50		7.43		7.53		7.45		7.n		7.69		7.58		7.u	
01/20/94	3.9		7.73		7.61		7.65		7.56		7.49		7.77		7.73		7.64		7.54
01/25/94	4.1	7.80		7.66		7.78		7.64		7.54		7.86		7.76		7.66		7.53	
01/27/94	4.0		7.83		7.68		7.74		7.67		7.58		7.88		7.83		7.71		7.61
02/01/94	2.3	7.80		7.72		7.72		7.69		7.62		7.89		7.80		7.71		7.57	
02/03/94	2.1		7.82		7.55		7.R		7.w		7.59		7.84		7.81		7.R		7.63
02/08/94	2.2	7.83		7.74		7.74		7.67		7.64		7.K		7.80		7.75		7.66	
02/10/94	3.6		7.88		7.w		7.81		7.77		7.72		7.91		7.90		7.K		7.73
02/15/94	4.2	7.K		7.76		7.n		7.76		7.w		7.98		7.92		7.80		7.67	
02/17/94	5.4		7.m		7.76		7.n		7.76		7.w		7.98		7.92		7.80		7.67

APPENDIX D

Total feed fed per month to experimental raceways during the rearing periods from 1990 to 1994.

	Kg food per month per raceway													
	Al	A2	B1	B2	Cl	C2	D1	D2	El	E2	F1	F2	G1	G2
1990-1991														
September	652.3	657.7	374.5	378.6	644.1	690.5	1515.0	1565.9	741.8	765.9	810.9	791.8	730.3	759.5
October	326.8	222.3	213.2	136.8	343.6	249.5	7K.3	w . 5	224.1	244.1	359.1	379.1	318.2	376.8
November	305.0	239.1	133.2	180.5	296.4	270.0	643.2	600.9	251.4	232.3	275.9	295.2	270.0	295.5
December	w . 3	130.0	w . 5	W . 9	130.9	148.2	302.3	310.0	109.1	110.9	117.7	121.8	108.6	112.7
January	130.0	112.3	84.1	78.2	125.9	139.5	242.7	239.1	114.1	ill.8	106.8	114.1	110.0	107.7
February	274.5	261.8	100.5	179.5	281.4	3D2.3	565.0	591.4	277.4	282.7	265.0	280.9	255.9	266.8
1991-1992														
August	422.3	366.4	226.8	225.0	418.6	409.1	965.0	801.8	482.3	503.2	490.0	491.8	540.9	551.8
September	504.5	4n.o	2a7.7	25a.2	503.6	520.0	1179.5	1166.5	4ai.a	499.1	549.5	526.4	am.6	5a7.7
October	399.5	3x.4	256.8	265.0	437.3	424.5	999.5	944.5	396.8	387.7	442.3	460.5	457.3	479.5
November	X3.6	311.4	166.8	165.0	343.6	367.7	785.9	716.8	330.0	320.5	357.3	372.3	414.1	414.5
December	243.6	223.2	132.3	138.6	242.7	224.5	511.8	506.4	211.4	203.6	219.5	a . 6	241.8	248.6
January	191.4	197.3	123.2	150.5	201.8	198.6.	424.5	426.4	192.7	192.3	2W.4	210.9	237.3	226.4
February	298.6	278.2	1W.I	200.0	286.4	28D.D	652.7	631.8	278.6	271.4	266.4	280.5	297.3	292.7

	Kg food per month per raceway													
	A1	A2	B1	B2	C1	C2	D1	D2	E1	E2	F1	F2	G1	G2
1992-1993														
August	540.9	sss.0	2W.1	393.2	544.1	579.1	1462.3	luQ.Q	613.6	618.2	636.8	596.8	598.6	594.1
September	526.4	461.8	209.5	199.5	so3.6	408.2	1391.8	1439.9	572.7	w7.3	583.2	575.9	616.4	616.4
October	293.2	336.9	299.9	|W.|	344.1	345.5	t993.2	1958.2	w3.6	577.7	566.8	511.4	585.0	606.9
November	247.6	235.0	135.9	135.9	235.0	235.9	677.3	679.5	296.8	295.0	354.5	328.2	335.5	346.2
December*	53.2	50.0	26.2	26.2	49.5	50.9	lw.s	151.4	58.2	60.0	64.5	58.2	56.8	59.5
January	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
February	187.8	206.9	123.1	117.2	192.6	204.6	481.3	475.1	194.6	190.8	194.1	192.7	206.5	190.4
March*	126.6	126.6	54.1	85.0	96.4	67.3	2S6.8	246.4	9S.0	99.9	192.3	91.8	105.0	90.0
1993-1994**														
August	NA	398.6	NA	235.9	NA	365.0	NA	901.4	394.1	NA	455.5	NA	381.8	NA
September	NA	451.4	NA	257.3	NA	485.0	NA	1260.5	492.7	NA	556.4	NA	544.5	NA
October	NA	375.9	NA	146.8	NA	369.5	NA	1143.2	493.6	NA	485.0	NA	471.4	NA
November	NA	152.7	NA	loo.9	NA	149.1	NA	330.9	102.7	NA	120.9	NA	135.5	NA
December	NA	112.7	NA	R.7	NA	193.2	NA	81.8	101.4	NA	192.7	NA	110.0	NA
January	NA	146.8	NA	93.6	NA	143.6	NA	369.9	142.3	NA	lsoo.o	NA	lb.9	NA
February	NA	113.6	NA	64.S	NA	116.4	NA	264.5	192.3	NA	109.1	NA	119.5	NA

* Entir8 month not included.

"Fad amounts for only half the experimental raceways was available.